Control System Design and Commissioning for a Model of a Lifter Vehicle

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Bachelor's thesis

Degree programme in Mechanical Engineering and Production Technology

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ABSTRACT

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ABSTRACT

In order to make a convenient and fast transportation system in the real factory, a small scale model of the solution can be designed and made first. In this thesis a control system was designed for a remote controlled self navigating vehicle and for a warehouse. In another thesis by Mr. Priit Veia the construction of the vehicle models was designed. The control system will be installed and commissioned in these small scale models.

According to the variations in the factory layout three versions of the control system were designed. Because of the time limitation, only versions 1 and 3 were designed in detail and constructed. In version 1 a traditional wired control system was used. In version 3 a wireless communication was used.

As a conclusion, two different control systems were done with different benefits. Version 1 could be the simplest solution for the transportation system. And version 3 does not need complicated navigation because the transportation system with wireless communication is following a predefined path on the floor.

Keywords Control system, PLC, vehicle, commissioning, mechatonics.

Pages 60 p. + appendices 5 p.

CONTENTS

1 INTRODUCTION

In the factory, transporting freights into and out from or through the warehouse is usually done manually. Ordinarily, worker needs to drive the loading vehicle for transporting several times a day. However, this situation can be considered as wasting manpower, material resources and time. Therefore, an efficient loading and transporting system is needed.

However, because a prototype of the real transporting system could be very big and costs a lot, a small scale model of the solution can be designed and made first. In the simulated factory, there are some cassettes that will be loaded into a transportation vehicle and transported to a destination. The cassettes are constructed so, that the vehicle can lift those without a need of any supporting equipment like fork lift or crane.

Commercial solutions for this kind of transportation system are on the market. Products can be found from companies TTSGROUP and LOGISTER. A typical “translifter” can be seen on pictures below.

FIGURE 1.1 An example of the translifter. /1/

In this thesis a control system will be designed for the transportation system. In another thesis by Mr. Priit Veia the construction of the vehicle models will be designed. The transportation system model will be used for training on control systems and electric drives.

A **control system** is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems. In a more understandable way, a control system is used to control a machine or a system in an established pattern. /2/

In the real life, there could be different kinds of factory layouts and other requirements for the remote controlled or the automatic transportation systems. Therefore, three different solutions will be designed.

The common condition for these three solutions is that the transporting vehicle is controlled by a control pendent and loading/unloading cassette at the end of the moving path. The different segments are:

Version 1: Transporting freights on a straight and fixed track
Version 2: Transporting freights in a straight path
Version 3: Transporting freights between two destinations following a predefined path.

The control system requirements will be given for all three different versions. The technical details and total cost for control system components will be studied. The total cost of the control system will be studied based on the requirements for all three versions. But only versions 1 and 3 will be designed in detail and constructed.

2 OVERALL DESIGN

This section will give a rough idea of the control system and the layout for the three versions. Based on the setting conditions for those three versions, the layout and the overall idea of each version will be presented separately.

2.1 OVERALL DESIGN FOR VERSION 1

The overall idea of the whole system can be seen from *Figure 2.1.* Since the objective of this thesis is designing a control system for the transportation system, more attention needs to be paid to the control system which includes the control cabinet, control pendant and parts of the vehicle.

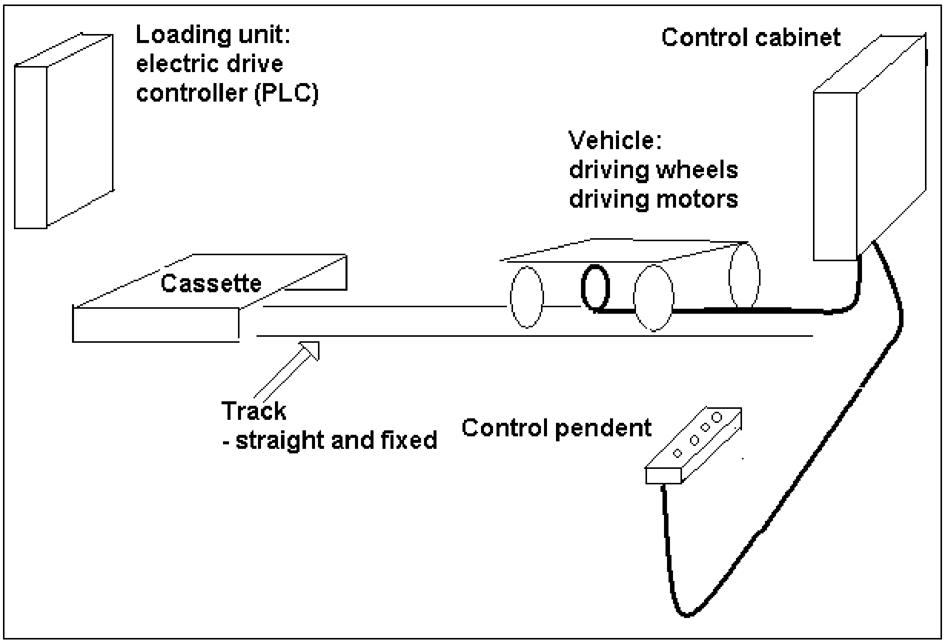


FIGURE 2.1 The overall outline of the whole transportation system.

Based on the outline of the transportation system of version 1, the overall idea comes as follows:

1. All the movements can mostly be controlled by the control pendant.
2. The vehicle can move in two directions: forward and backwards.
3. The vehicle will lift up the cassette at the end of the track controlled by the control pendent.
4. The vehicle will unload the cassette in the destination port by the control pendent.

In accordance with those issues listed above, further design will be made and expatiated in the FUNCTIONAL DESCRIPTION (*Section 4.1*) and SYSTEM DESCRIPTION (*Section 5.1*).

2.2 OVERALL DESIGN FOR VERSION 2

In version 2, the control system is controlled by the control pendent, and the vehicle is moving in a straight path with a wireless connection. The wireless control is used in this case to avoid the harm on having cables or rails on the factory floor. See the simplified layout of version 2 in *Figure 2.2*.

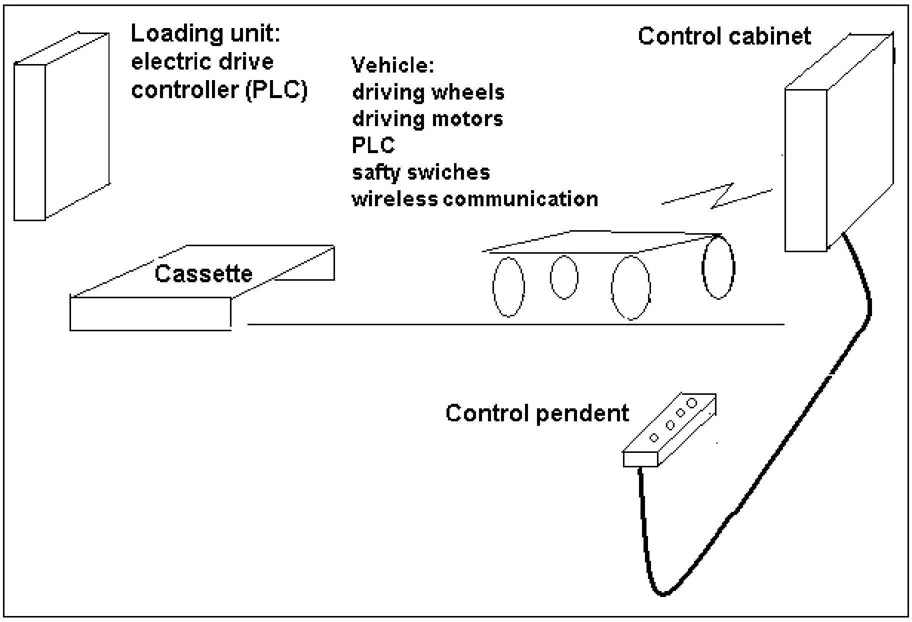


Figure 2.2 Simplified layout of the transportation system for version 2.

Based on the outline of the transportation system of version 2, the overall idea comes as follows:

1. All the movements can mostly be controlled by the control pendant.
2. The vehicle can move forward and backwards.
3. The vehicle will lift up the cassette at the end of the track controlled by the control pendent.
4. The vehicle will unload the cassette in the destination port by the control pendent.

Version 2 will not be designed in detail and constructed.

2.3 OVERALL DESIGN FOR VERSION 3

The main idea of version 3 is controlling a vehicle in a predefined path and loading a cassette at the end of the path with a wireless connection. The wireless control is used in this case to avoid the harm on having cables or rails on the factory floor. *Figure 2.2* gives a sketch of the transportation system.

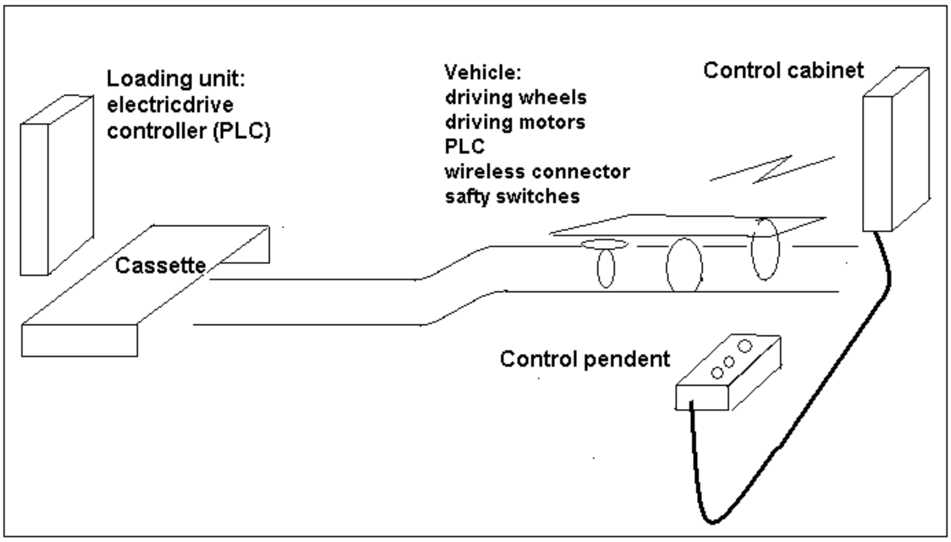


FIGURE 2.3 Sketch of the transportation system and moving path.

Based on the outline of the transportation system of version 3, the overall idea comes as follows:

5. All the movements can mostly be controlled by the control pendant.
6. The vehicle can move forward and backwards.
7. The vehicle has the ability to detect the predefined path.
8. The vehicle has the ability to turn.
9. The vehicle will lift up the cassette at the end of the track controlled by the control pendent.
10. The vehicle will unload the cassette in the destination port by the control pendent.

In accordance with those issues listed above, further design will be made and explained in the FUNCTIONAL DESCRIPTION (*Section 4.2*) and SYSTEM DESCRIPTION (*Section 5.2*).

3 MAIN COMPONENTS

Before the detailed design of the transportation system the main components used in the system can be decided first. Because most of the main components used in Version 1, Version 2 and Version 3 are the same, they will not be listed separately.

3.1 DC MOTORS

A **DC motor** is an electric motor that runs on direct current (DC) electricity. In this control system, the motor will run in both directions and in certain applications with variable speed. For keeping the total cost and number of components as low as possible the same type of motor is used for most applications.
Nominal voltage +12V;
Nominal power 40W;
Nominal current +10A;
And weight as light as possible.

FIGURE 3.1 A typical DC motor with gear assembly./3/

3.2 PROGRAMMABLE LOGIC CONTROLLER (PLC)

A **Programmable Logic Controller** (PLC) is a digital electronic that uses a programmable memory to store instructions and implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes and has been specifically designed to make programming easy. /4/ (W.BOLTON, 2004, 444)

A PLC is an example of a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result. (*Figure 3.2*) Input/output (or I/O), refers to the communication between an information processing system, and the outside world. Inputs are the signals or data received by the system, and outputs are the signals or data sent from it.

FIGURE 3.2 A typical PLC with 8 inputs and 4 outputs and Ethernet connection./5/

3.3 PROXIMITY SENSOR

A **proximity sensor** is a sensor able to detect the presence of nearby objects without any physical contact. A proximity sensor often emits an electromagnetic or electrostatic field, or a beam of electromagnetic radiation (infrared, for instance), and looks for changes in the field or return signal. Different proximity sensor targets demand different sensors. For example, a capacitive or photoelectric sensor might be suitable for a plastic target; an inductive proximity sensor requires a metal target. /6/
Based on the material used on the cassette and on the other structures and objects, inductive sensors and mechanical switches are typically the most economical solution. (*Figure 3.3)*

FIGURE 3.3 Inductive sensors can be used in the vehicle./7/

Inductive proximity sensors are used for non-contact detection of metallic objects. Their operating principle is based on a coil and oscillator that creates an electromagnetic field in the close surroundings of the sensing surface. The presence of a metallic object (actuator) in the operating area causes a dampening of the oscillation amplitude. The rise or fall of such oscillation is identified by a threshold circuit that changes the output of the sensor./8/

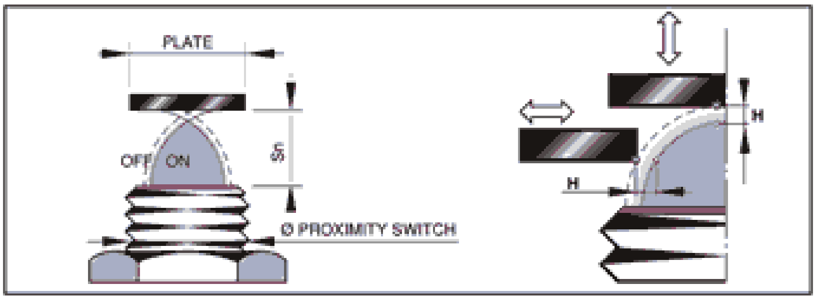


Figure 3.4 Operating principle of the inductive sensor. /8/

This inductive sensor will be used for detecting the cassette in the transportation system for all three versions. Besides, for version 3, it will be used also for detecting the predefined path. The predefined path in version 3 will be marked with metal tape on the floor. As *Figure 3.4* shows, if the inductive sensor is above the metal tap on the floor, the output will be ON, otherwise it will be OFF.

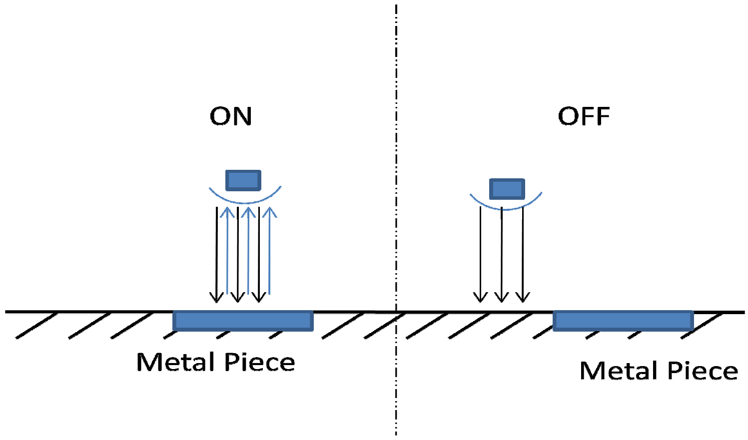


FIGURE 3.5 Working method of the inductive sensor.

3.4 RELAY

A **relay** is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism, but other operating principles are also used. Relays find applications where it is necessary to control a high power circuit by a low-power signal, or where several circuits must be controlled by one signal. /9/

FIGURE 3.6 A relay with two turning positions and two connecting ports./10/

In this project, the relays will control all the movements of motors, like the direction of the motor and the power supply for the motor.

3.5 LIMIT SWITCHES

Switches are commonly employed as input devices to indicate the presence or absence of a particular condition in a system or process that is being monitored and/or controlled. In motorized electromechanical systems, limit switches provide the function of making and breaking electrical contacts and consequently electrical circuits. A limit switch is configured to detect when a system's element has moved to a certain position. Limit switches are typically utilized in industrial control applications to automatically monitor and indicate whether the travel limits of a particular device have been exceeded. /11/

There are many models are available of limit switches, such as those resistant to head, cold, or corrosion, as well as high-precision models. (*Figure 3.7*)

FIGURE 3.7 Models of limited switches. /12/

3.6 EMERGENCY STOP

Emergency stop switches are devices that users manipulate to initiate the complete shutdown of a machine, system, or process. Unlike regular stop switches, emergency stop switches are not solely dependent on springs. Instead, they generate electrical signals that latch the actuator. /13/

On large industrial machines, an emergency stop button is typically located on the panel, and possibly in several other areas of the machine. This provides a fast means to disconnect the energy source of the device to protect workers. In some contexts, such as nuclear reactors or data centers, the emergency stop is known as scram./14/

In this project, a pushbutton emergency stop will be used as in the large industrial machine. (*Figure 3.8*)

FIGURE 3.8 Emergency Stop button on the control pendent/15/

4 FUNCTIONAL DESCRIPTION

4.1 FUNCTIONAL DESCRIPTION OF VERSION 1

In version 1, because the vehicle is moving follow a fixed and straight track, a control cabinet with a PLC and power supplies can connect with the vehicle by a cable.

As mentioned before, mostly movements are controlled by a control pendent which connects with the control cabinet. Therefore, an operator only needs to control the vehicle with the control pendent in a visible place to the vehicle. As the path of the transporting is a straight and fixed track, the vehicle can be seen everywhere surrounding the whole transportation system. In this case, the operator can stay anywhere with the limited length of the control pendent's cable.

All electrical components used in the vehicle and the control pendent are connected with the PLC. In this case, all components can treat as inputs and outputs for the PLC. The input and output signals in the vehicle connect to the PLC through the Ethernet. A program will transmit into the PLC later for controlling the transportation system. The power for the PLC and all electrical components is given by a power supply which has +24 V in the control cabinet.

A motor (motor 1) in the warehouse is used to put freights into the cassette. The power supply with +12 V for this motor is given from the control cabinet and controlled by a relay (relay 1) in the control cabinet. In order to protect this motor, a fuse (fuse 1) can install between the power supply and this motor.

In the vehicle, there are two motors (motor 2 and 3) installed separately in two wheels for driving the vehicle forward and backwards. The direction of wheels can be controlled by two relays (relay 3 and 4). The command will give from the control pendent through the PLC to both relays when needs to change direction. The power supply with +12 V for both motors is given from the control cabinet and cut by a relay (relay 2) in the vehicle. In order to protect motors, two fuses (fuse 2 and 3) can be installed between the power supply and these two motors (Figure 4.1).

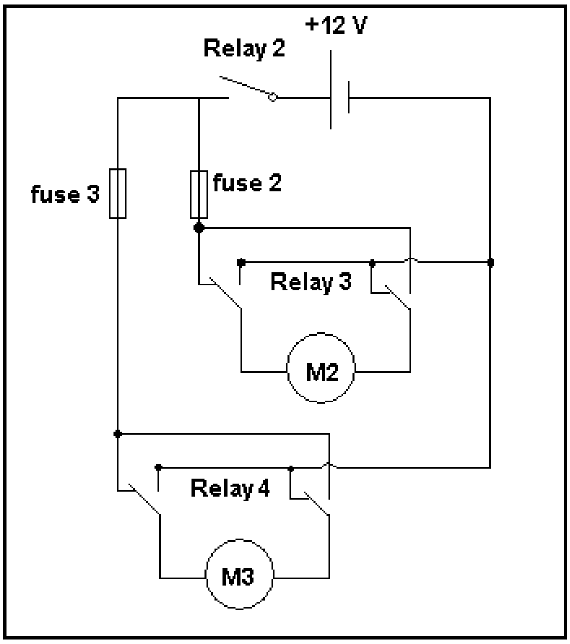


Figure 4.1 Circuit diagram for two driving motors in the vehicle.

Four limit switches (*Figure 4.2*) are installed in two edges of the vehicle for the safety factor. There are four springs parallel connecting with each switch for buffering the impact in both directions. If a block stops the vehicle during the movement, two of the limit switches near the block will touch the block and automatically cut the power supply for two driving motors (motor 2 and 3) which means turn the relay 2. Then the operator needs to remove the block on the track and make sure the situation is safe. She/he pushes the reset button in the control pendent will return the voltage to the drive system. The driving can be started again by pushing the corresponding button in the control pendent. The vehicle can be driven as well away from the blocking object by keeping the reset switch down and pushing the corresponding drive button.

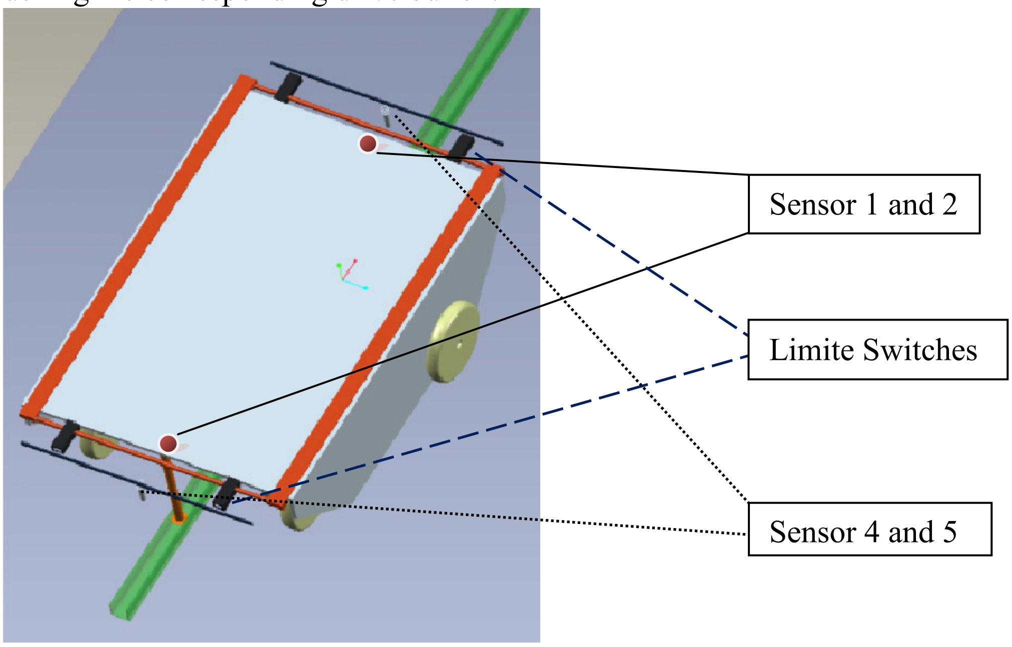


FIGURE 4.2 Layout of limited switches and sensors on the vehicle for Version 1.

Two inductive sensors (sensor 1 and 2) are installed on two edges of the vehicle. When the vehicle moving under a cassette, these two inductive sensors will detect the vehicle and sent signals to the PLC. Then the PLC will stop the vehicle by turning the relay 2 automatically. This movement can be seen in the control pendent by an indicator (indicator 1).

One extra motor (motor 4) is installed in the vehicle for the lifting purpose. The supplied voltage comes from the +12 V power supply in the control cabinet and is protected by a fuse (fuse 4). This motor is put in the vertical position and moving up or down controlled by a relay (relay 5). After getting the signal from indicator 1, which means the vehicle is stopping under the vehicle, the operator can push the corresponding button on the control pendent to turn the relay 4 for lifting up. The power for this motor is also given by the control cabinet with a +12 V power supply. In order to make sure this motor lifts the vehicle up completely, a sensor (sensor 3) is put at the end of this motor. This sensor will detect the motor when it lifts up completely, and, an indicator (indicator 2) in the control pendent will light up. For unloading, a push button is used in the control pendent to turn the relay 5 and move down this motor 4.

Two extra inductive sensors (sensor 4 and 5) lay on both end of the vehicle (*Figure 4.2)* for detecting cassettes in front of the vehicle. If one of these sensors detects a cassette in front of the vehicle when it is loading, the vehicle will stop automatically by turning the relay 2 through the program in the PLC for protecting the vehicle from the impact between both cassettes.

Based on description above, buttons and indicators in the control pendent can be listed as follow:
1. One emergency stop to cut power supply to motors.
2. ON-OFF switch to give power supply to motors.
3. Two pushbuttons to control the direction of the vehicle.
4. Two pushbuttons to control the loading unit in the vehicle.
5. Two indicators to show the vehicle stop under a cassette or lifting up.

4.2 FUNCTIONAL DESCRIPTION OF VERSION 3

Firstly, mostly movements are controlled by a control pendent which connects with the control cabinet. However, because version 3 is wireless connection between the control cabinet and the vehicle, a distance sensor needs to be put on the vehicle for detecting the real distance the vehicle moves. The pulse signals from the distance sensor are counted in a sensor card in the vehicle PLC. The vehicle PLC gets the counted position which will be read by the main PLC in the control cabinet over the wireless link. A computer will connect to the main PLC and show the counted position to the operator. In this case, the operator can stays anywhere with the limited length of the control pendent's cable but also can see the computer.

The vehicle in version 3 is moving follow a predefined path on the floor, and, wireless connection between the vehicle and the control cabinet. Therefore, two independent PLCs need to be put in the control cabinet and in the vehicle separately. In this case, this control system can be treated as two parts. Part one is the control cabinet which connects with the control pendent. And part two is the vehicle.

In part one, a power supply with +24 V for the PLC (PLC 1) and other electrical components in the control cabinet and the control pendent needs to be installed in the control cabinet. A wireless connector is also needed in the control cabinet for communication with the vehicle.

A motor (motor 1) in the warehouse is used to put freights into the cassette. The power supply with +12 V for this motor is given from the control cabinet and controlled by a relay (relay 1) in the control cabinet. In order to protect this motor, a fuse (fuse 1) can install between the power supply and this motor.

In part two, there is a 12 V battery in the vehicle. This battery is used for supplying power for motors in the vehicle. A converter transfer 12 V to 24 V is used for supplying power for the control system components include a PLC (PLC 2), wireless connector and other electrical components in the vehicle.

In the vehicle, two motors (motor 2 and 3) driving the vehicle are separately controlled by two DC motor controllers. The DC motor controller can change the speed and direction (forward or backwards) of the motor, and both can be controlled by a potentialmeter in the control pendent. The power for motors, as said before, is given from the +12 V power supply in the vehicle. The command to the DC motor controller comes from the PLC 2 in the vehicle. One relay (relay 2) uses for cutting the power supply to motors.

Four inductive sensors (S1, S2, S3 and S4) that lay on the vehicle and face to the ground are used to detect the predefined path on the floor. As the draft drawing *Figure 4.3* shown, sensors 1and 2 are used to detect the path when the vehicle moves forward, and sensors 3 and 4 are used to detect the path when the vehicle moves backwards. Each sensor has the corresponding indicator in the control pendent (indicator 1, 2, 3 and 4). When the sensor is activated which means the vehicle is turning out of track or approaching the track corner, the vehicle will turn automatically by the differential speeds between these two motors. As an example in *Figure 4.4*, when the vehicle is moving forward and in a corner, sensor 1 will get a return signal from the floor and sent signal to the sub PLC. The signal through the program in the PLC will show on indicator 1 on the control pendent. Contrarily, sensors 3 and 4 exert the same action in opposite moving position of the vehicle.

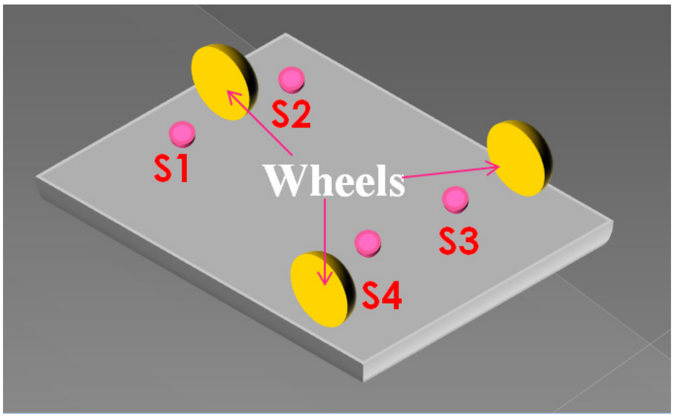


FIGURE 4.3 Layout of limited switches and sensors on the vehicle.

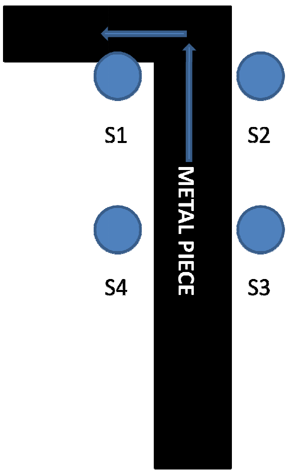


FIGURE 4.4 Example to show the method of the turning vehicle.

A safety system with four limit switches is built in the vehicle for protecting the vehicle and driving motors if a block stops the vehicle (Figure 4.5). There are four springs parallel connecting with each switch for buffering the impact in both directions. If a block stops the vehicle during the movement, two of the limit switches near the block will touch the block and automatically cut the power supply for two driving motors (motor 2 and 3) which means turn the relay 2. Then the operator needs to remove the block on the track and make sure the situation is safe. She/he pushes the reset button in the control pendent will return the voltage to the drive system. The driving can be started again by pushing the corresponding button in the control pendent. The vehicle can be driven as well away from the blocking object by keeping the reset switch down and pushing the corresponding drive button.

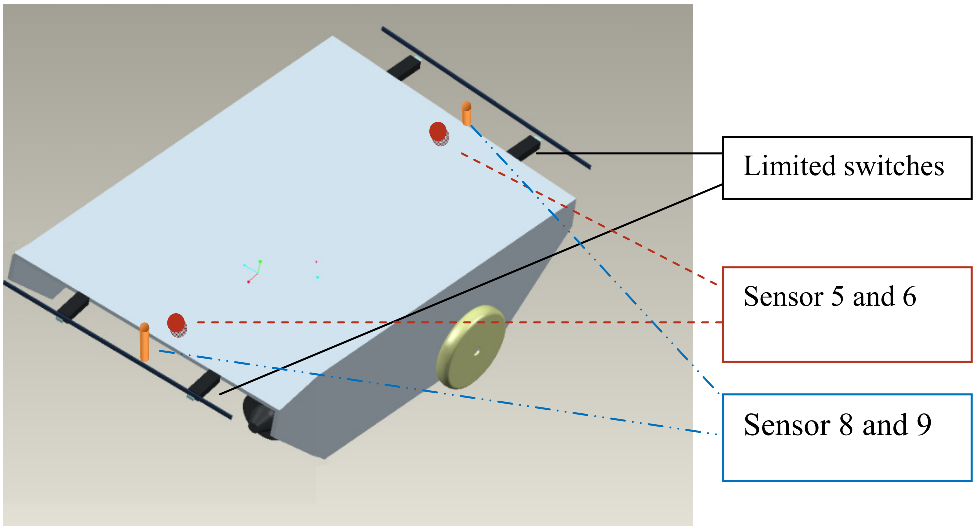


FIGURE 4.5 Layout of limited switches and sensors on the vehicle for Version 3.

Two inductive sensors (sensor 5 and 6) are installed on two edges of the vehicle (Figure 4.5). When the vehicle moving under a cassette, these two inductive sensors will detect the vehicle and sent signals to the PLC. Then the PLC will stop the vehicle by turning the relay 2 automatically. This movement can be seen in the control pendent by an indicator (indicator 5).

One extra motor (motor 4) is installed in the vehicle for the lifting purpose. This motor is put in the vertical position and moving up or down controlled by a relay (relay 3). After getting the signal from indicator 5, which means the vehicle is stopping under the vehicle, the operator can push the corresponding button on the control pendent to turn the relay 3 for lifting up. The power for this motor is also given by battery with +12 V in the vehicle. In order to make sure this motor lifts the vehicle up completely, a sensor (sensor 7) is put at the end of this motor. This sensor will detect the motor when it lifts up completely, and, an indicator (indicator 6) in the control pendent will light up. For unloading, a push button is used in the control pendent to turn the relay 3 and move down this motor 4.

Two extra inductive sensors (sensor 8 and 9) lay on both end of the vehicle (*Figure 4.5)* for detecting cassettes in front of the vehicle. If one of these sensors detects a cassette in front of the vehicle when it is loading, the vehicle will stop automatically by turning the relay 2 through the program in the PLC for protecting the vehicle from the impact between both cassettes.

Based on description above, buttons and indicators can be listed as follow:

1. One emergency stop to cut power supply to motors.
2. ON-OFF switch to give power supply to motors.
3. One potential meter to control the turning movement of the vehicle.
4. Two pushbuttons to control the direction of the vehicle.
5. Two pushbuttons to control the loading unit in the vehicle.
6. Two indicators to show the vehicle stop under a cassette or lifting up.
7. Four indicators to show which sensor for the turning purpose get a return signal from the ground.

5 SYSTEM DESCRIPTION

5.1 SYSTEM DESCRPTION OF VERSION 1

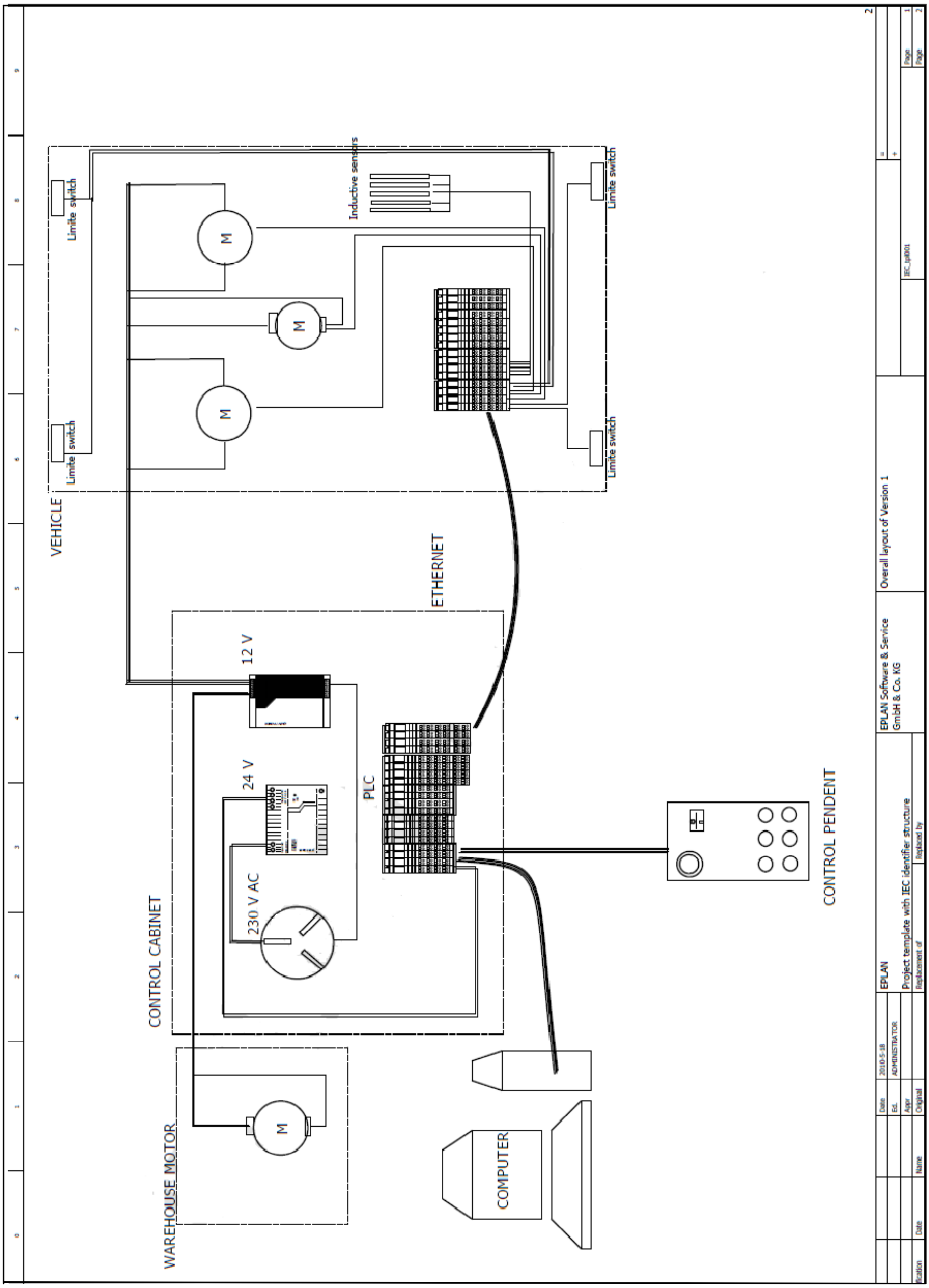


FIGURE 5.1 Layout of all the connecting components in Version 1

5.1.1 SENSORS

Name	Type	Location	Description
S1	Inductive sensor	Vehicle	Works together with S2 for detecting the cassette need to be loaded. Once both are ON, the vehicle will stop.
S2	Inductive sensor	Vehicle	Works together with S1 for detecting the cassette need to be loaded. Once both are ON, the vehicle will stop.
S3	Tactile sensor	Vehicle	Detecting the lifting motor is completely up.
S4	Inductive sensor	Vehicle	Detect cassette in front of the vehicle when moving forward. When the vehicle is loading and this sensor is ON, the vehicle will stop.
S5	Inductive sensor	Vehicle	Detect cassette in front of the vehicle when moving backwards. When the vehicle is loading and this sensor is ON, the vehicle will stop.

5.1.2 CONTROL PENDENT

Name	**Type**	**Mark**	**Description**
Emergency Stop	Push	/	Immediately cut power supply to motors for emergency situation.
ON-OFF switch	/	/	Switch for giving power supply to motors.
Forward	Pushbutton	F	Order vehicle running forward.
Backwards	Pushbutton	B	Order vehicle running backwards.
Loading	Pushbutton	L	Order vehicle loading the cassette.
Unloading	Pushbutton	U	Order vehicle unloading the cassette.
Start loading	Indicator	S	Tell operator can start to load the cassette.
Lifting up	Indicator	L	Show the vehicle is lifting up.

5.1.3 RELAY

Name	**Location**	**Description**
R1	Control cabinet	Control the power supply to the motor in the warehouse.
R2	Vehicle	Control the power supply to the two driving motors in the vehicle.
R3	Vehicle	Control the direction of the left driving motor.
R4	Vehicle	Control the direction of the right driving motor.
R5	Vehicle	Control the lifting motor loading or unloading.

5.1.4 LIMIT SWITCHES

Name	Location	Description
LS1	vehicle	Limited switch for stopping motors automatically with a block. Limited switch for stopping motors automatically with a block.
LS2	vehicle	Limited switch for stopping motors automatically with a block.
LS3	vehicle	Limited switch for stopping motors automatically with a block.
LS4	vehicle	Limited switch for stopping motors automatically with a block.

5.1.5 INPUTS/OUTPUS FOR PLC

NOTE:

The symbol for all inputs will start with an acronym for the purpose of the input.

Acronym	Coming from words	Explanation
PB	Pendant Button	Operator control button on the control pendant
PSw	Pendant Switch	Selection switch on the control pendant
PIL	Pendant Indicator Light	
SSw	Sensor Switch	A proximity or mechanical switch
SEnc	Sensor Encoder	Pulse encoder or absolute encoder
RO	Relay Output	
TO	Transistor Output	

*Setting four or eight rows as a group in a table. The reason is the normative input/output numbers in a PLC is four or eight terminal points as a group.

5.1.5.1. INPUT LIST FOR PLC

Symbol	Address	Variable Type	PLC unit	Description
PBEmergency Stop	% I 1.1	BOOL	Control pendent, digital input	Push button to stop power supply immediately.
PSwOn	% I 1.2	BOOL	Control pendent, digital input	On-off switch to supply voltage to the system.
PBForward	% I 1.3	BOOL	Control pendent, cabinet input	Pushbutton to drive the vehicle forward.
PBBackwards	% I 1.4	BOOL	Control cabinet, digital input	Pushbutton to drive the vehicle backwards.
PSwLoading	% I 2.1	BOOL	Control cabinet, digital input	Switch to control the motor loading.
PSwUnloading	% I 2.2	BOOL	Control cabinet, digital input	Switch to control the motor unloading.

Symbol	**Address**	**Variable Type**	**PLC unit**	**Description**
SSwForwar-dUnder	% I 3.1	BOOL	Vehicle control, digital input	A proximity sensor to detect whether there is a cassette in front of vehicle.
SSwBackward-sUnder	% I 3.2	BOOL	Vehicle control, digital input	A proximity sensor detect whether there is a cassette in front of vehicle.
SSwForwar-dReach	%I 3.3	BOOL	Vehicle control, digital input	A proximity sensor to make sure the vehicle is under the cassette.
SSwBack-wardsReach	%I 3.4	BOOL	Vehicle control, digital input	A tactile sensor to detect whether the loading part is lifted up.
SSwFor-wardStopLeft	% I 4.1	BOOL	Vehicle control, digital input	A limit switches to cut the power supply if any baulks hit the vehicle.
SSwFor-wardStopRight	% I 4.2	BOOL	Vehicle control, digital input	Limit switch to cut the power supply if any baulks hit the vehicle.
SSwBack-ewardsStopLeft	% I 4.3	BOOL	Vehicle control, digital input	Limit switch to cut the power supply if any baulks hit the vehicle.
SSwBack-wardsSto-pRight	% I 4.4	BOOL	Vehicle control, digital input	Limit switch to cut the power supply if any baulks hit the vehicle.
Symbol	**Address**	**Variable Type**	**PLC unit**	**Description**
SSwLiftingup	%I 5.1	BOOL	Vehicle control, digital input	Tactile sensor to detect the lifting motor is completely up.
SEncDistance	% I 5. 2	BOOL	Vehicle control, digital input	A pulse sensor to detect how far does the vehicle move.

5.1.5.2. OUTPUT LIST FOR PLC

Symbol	**Address**	**Variable Type**	**PLC unit**	**Description**
PILStartLoad	%Q 1.1	BOOL	Control pendent indicator, digital output	Blue indicator to show the trolley is under the cassette.
PILLifting	%Q 1.2	BOOL	Control pendent indicator, digital output	Yellow indicator to show the vehicle is lifted up.
TODistance	%Q 1.3	BOOL	Transistor output	Detect how long does the vehicle move by counting the signal.

Symbol	**Address**	**Variable Type**	**PLC unit**	**Description**
ROWarehouse	%Q 2.1	BOOL	Vehicle control, digital output	Relay to give the power supply to both driving motors.
RORunvehicle	%Q 2.2	BOOL	Vehicle control, digital output	Relay to give the power supply to both driving motors.
RODirection	%Q 2.3	BOOL	Vehicle control, digital output	Relay to change the direction of the moving vehicle.
RODirection	%Q 2.3	BOOL	Vehicle control, digital output	Relay to change the direction of the moving vehicle.
ROLoading	%Q 2.4	BOOL	Vehicle control, digital output	Relay to control the loading motor lifting up.

5.2 SYSTEM DESCRIPTION FOR VERSION 3

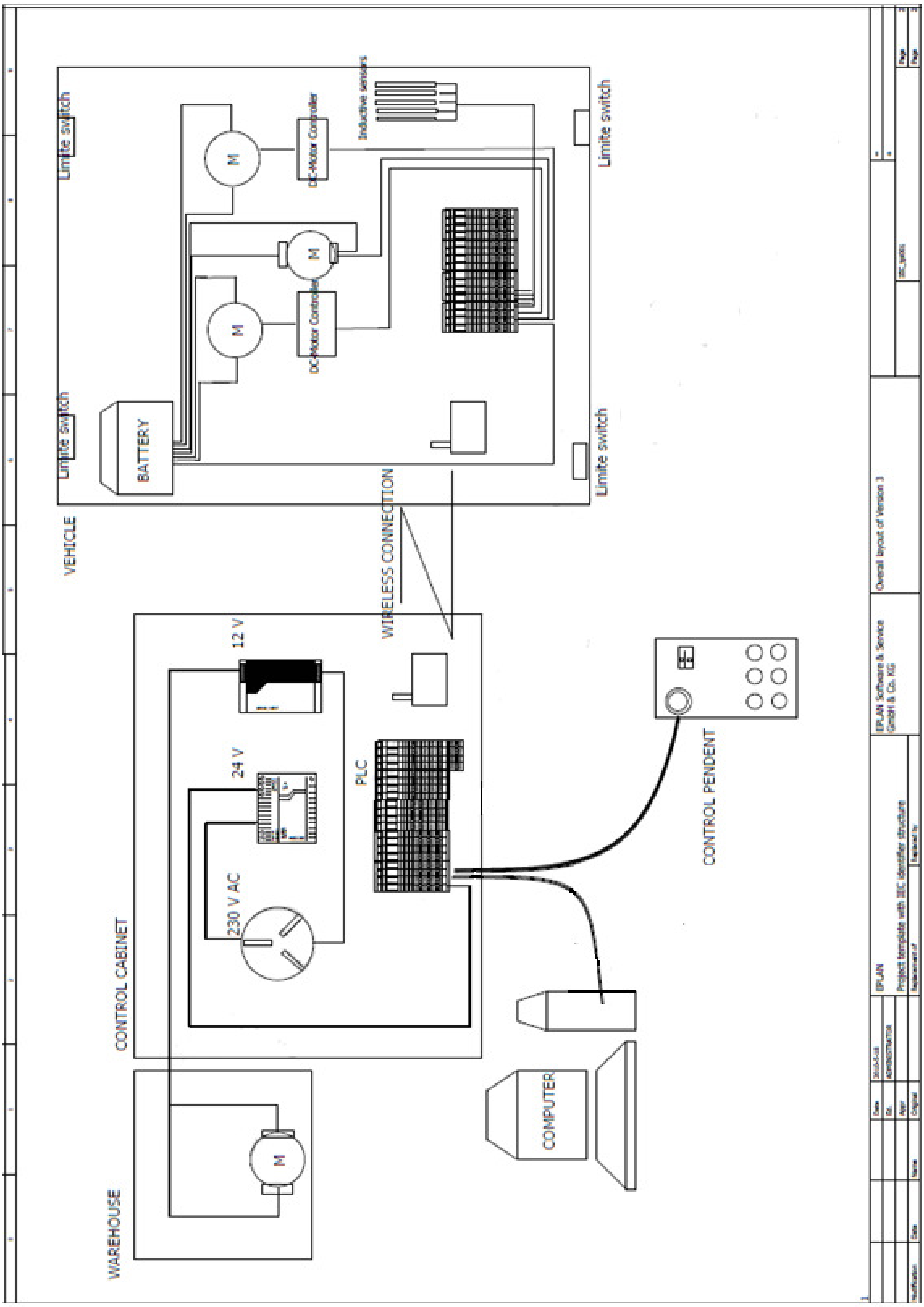


FIGURE 5.2 Layout of all the connecting components in Version 3

5.2.1 SENSORS

Name	**Type**	**Location**	**Description**
S1	Inductive sensor	Vehicle	Works together with S2 for detecting the line on the floor when vehicle is moving forward. If the guiding line turns left, this sensor will detect the line and send turning requirement to the operator in the control pendent.
S2	Inductive sensor	Vehicle	Works together with S1 for detecting the line on the floor when vehicle is moving forward. If the guiding line turns right, this sensor will detect the line and send turning requirement to the operator in the control pendent.
S3	Inductive sensor	Vehicle	Works together with S4 for detecting the line on the floor when vehicle is moving backwards. If the guiding line turns left, this sensor will detect the line and send turning requirement to the operator in the control pendent.
S4	Inductive sensor	Vehicle	Works together with S3 for detecting the line on the floor when vehicle is moving backwards. If the guiding line turns right, this sensor will detect the line and send turning requirement to the operator in the control pendent.
S5	Inductive sensor	Vehicle	Works together with S6 for detecting the cassette need to be loaded. Once both are ON, the vehicle will stop.
S6	Inductive sensor	Vehicle	Works together with S5 for detecting the cassette need to be loaded. Once both are ON, the vehicle will stop.
S7	Tactile sensor	Vehicle	Detecting the lifting motor is completely up.
S8	Inductive sensor	Vehicle	Detect cassette in front of the vehicle when moving forward. When the vehicle is load-ing and this sensor is ON, the vehicle will stop.
S9	Inductive sensor	Vehicle	Detect cassette in front of the vehicle when moving backwards. When the vehicle is loading and this sensor is ON, the vehicle will stop.

5.2.2 CONTROL PENDENT

Name	Type	Mark	Description
Emergency Stop	Push	/	Immediately cut power supply to motors for emergency situation.
ON-OFF switch	/	/	Switch for giving power supply to motors.
Forward	Pushbutton	F	Order vehicle running forward.
Backwards	Pushbutton	B	Order vehicle running backwards.
Loading	Pushbutton	L	Order vehicle loading the cassette.
Unloading	Pushbutton	U	Order vehicle unloading the cassette.
Start loading	Blue indicator	S	Tell operator can start to load the cassette.
Lifting up	Yellow indicator	L	Show the vehicle is lifting up.
Direction controller	Potentiometer	P	Turing the vehicle by controlling the differential speed of two driving motors.
ForwardLeft	Blue indicator	FL	Operational requirement sent from sensor 1 to turn potentiometer left.
ForwardRight	Blue indicator	FR	Operational requirement sent from sensor 2 to turn potentiometer right.
BackwardsLeft	Blue indicator	BL	Operational requirement sent from sensor 3 to turn potentiometer left.
Backwards-Right	Blue indicator	BR	Operational requirement sent from sensor 4 to turn potentiometer right.

5.2.3 RELAY

Name	Location	Description
R1	Control cabinet	Control the power supply to the motor in the warehouse.
R2	Vehicle	Control the power supply to the two driving motors in the vehicle.
R3	Vehicle	Control the lifting motor loading or unloading.

5.2.4 LIMIT SWITCHES

Name	Location	Description
LS1	vehicle	Limited switch for stopping motors automatically with a block. Limited switch for stopping motors automatically with a block.
LS2	vehicle	Limited switch for stopping motors automatically with a block.
LS3	vehicle	Limited switch for stopping motors automatically with a block.
LS4	vehicle	Limited switch for stopping motors automatically with a block.

5.2.5 DC-MOTOR CONTROLLER

Name	Location	Description
Left motor	Vehicle	Control the rotation speed of the left motor.
Right motor	Vehicle	Control the rotation speed of the right motor.

5.2.6 INPUTS/OUTPUTS FOR PLC

NOTE:

The symbol for all inputs will start with an acronym for the purpose of the input.

Acronym	Coming from words	Explanation
PB	Pendant Button	Operator control button on the control pendant
PSw	Pendant Switch	Selection switch on the control pendant
PIL	Pendant Indicator Light	
PMeter	Potential Meter	
DMControl	DC Motor controller	Control rotational speed of a motor
SSw	Sensor Switch	A proximity or mechanical switch
SEnc	Sensor Encoder	Pulse encoder or absolute encoder
RO	Relay Output	
TO	Transistor Output	

*Setting four or eight rows as a group in a table. The reason is the normative input/output numbers in a PLC is four or eight terminal points as a group.

9.2.5.1. INPUT LIST FOR PLC

Symbol	Address	Variable Type	PLC unit	Description
PBEmergency Stop	% I 1.1	BOOL	Control pendent, digital input	Push button to stop power supply immediately.
PSwOn	% I 1.2	BOOL	Control pendent, digital input	On-off switch to supply voltage to the system.
PBForward	% I 1.3	BOOL	Control pendent, cabinet input	Pushbutton to drive the vehicle forward.
PBBackwards	% I 1.4	BOOL	Control cabinet, digital input	Pushbutton to drive the vehicle backwards.
PSwLoading	% I 2.1	BOOL	Control pendent, digital input	Switch to control the motor loading.
PSwUnloading	% I 2.2	BOOL	Control pendent, digital input	Switch to control the motor unloading.
Symbol	**Address**	**Variable Type**	**PLC unit**	**Description**
PMeter	%I 3.1	BOOL	Control pendent, analog input	Potentiometer to control the direction of the vehicle

Symbol	Address	Variable Type	PLC unit	Description
SSwForwar-dleft	%I 4.1	BOOL	Vehicle control, digital input	Proximity sensor to detect the guiding line for left turning when moving for-ward.
SSwForwar-dright	%I 4.2	BOOL	Vehicle control, digital input	Proximity sensor to detect the guiding line for right turning when moving for-ward.
SSwBack-wardsleft	%I 4.3	BOOL	Vehicle control, digital input	Proximity sensor to detect the guiding line for left turning when moving back-wards.
SSwBack-wardsright	%I 4.4	BOOL	Vehicle control, digital input	Proximity sensor to detect the guiding line for right turning when moving back-wards.
SSwForwar-dUnder	% I 5.1	BOOL	Vehicle control, digital input	A proximity sensor to detect whether there is a cassette in front of vehicle.
SSwBack-wardsUnder	% I 5.2	BOOL	Vehicle control, digital input	A proximity sensor detect whether there is a cassette in front of vehicle.
SSwForwar-dReach	%I 5.3	BOOL	Vehicle control, digital input	A proximity sensor to make sure the vehicle is under the cassette.
SSwBack-wardsReach	%I 5.4	BOOL	Vehicle control, digital input	A tactile sensor to detect whether the loading part is lifted up.

Symbol	Address	Variable Type	PLC unit	Description
SSwFor-wardStopLeft	% I 6.1	BOOL	Vehicle con-trol, digital input	A limit switches to cut the power supply if any baulks hit the vehicle.
SSwFor-wardStopRight	% I 6.2	BOOL	Vehicle con-trol, digital input	Limit switch to cut the power supply if any baulks hit the vehicle.
SSwBack-ewardsStop-Left	% I 6.3	BOOL	Vehicle con-trol, digital input	Limit switch to cut the power supply if any baulks hit the vehicle.
SSwBack-wardsSto-pRight	% I 6.4	BOOL	Vehicle con-trol, digital input	Limit switch to cut the power supply if any baulks hit the vehicle.
SSwLiftingup	%I 7.1	BOOL	Vehicle con-trol, digital	Tactile sensor to detect the lifting motor is

			input	completely up.
SEncDistance	% I 7. 2	BOOL	Vehicle control, digital input	A pulse sensor to detect how far does the vehicle move.

9.2.5.2. OUTPUT LIST FOR PLC

Symbol	**Address**	**Variable Type**	**PLC unit**	**Description**
PILForwardLeft	%Q 1.1	BOOL	Control pendent indicator, digital output	Blue indicator to require operator turn potentiometer left when vehicle is moving forward.
PILForwardRight	%Q 1.2	BOOL	Control pendent indicator, digital output	Blue indicator to require operator turn potentiometer right when vehicle is moving forward.
PILBackwardsLeft	%Q 1.3	BOOL	Control pendent indicator, digital output	Blue indicator to require operator turn potentiometer left when vehicle is moving backwards.
PILBackwardsRight	%Q 1.4	BOOL	Control pendent indicator, digital output	Blue indicator to require operator turn potentiometer right when vehicle is moving backwards.
PILUnder	%Q 2.1	BOOL	Control pendent indicator, digital output	Blue indicator to show the trolley is under the cassette.
PILLifting	%Q2.2	BOOL	Control pendent indicator, digital output	Yellow indicator to show the vehicle is lifted up.
TODistance	%Q 2.3	BOOL	Transistor output	Detect how long does the vehicle move by counting the signal.

Symbol	**Address**	**Variable Type**	**PLC unit**	**Description**
ROWarehouse	%Q 2.1	BOOL	Vehicle control, digital output	Relay to give the power supply to both driving motors.
RORunvehicle	%Q 2.2	BOOL	Vehicle control, digital output	Relay to give the power supply to both driving motors.
ROLoading	%Q 2.4	BOOL	Vehicle control, digital output	Relay to control the loading motor lifting up.

Symbol	Address	Variable Type	PLC unit	Description
DMControlLeftmotor	%Q 3.1	BOOL	Vehicle control, analog output	DC-Motor controller to control the rotational speed of the left motor.
DMContorlrightmotor	%Q 3.2	BOOL	Vehicle control, analog output	DC-Motor controller to control the rotational speed of the right motor.

6 COMPARISON TABLES

After finishing the overall designing, the control system design team will communicate with the vehicle manufacturing team and tell them what they need to do and discuss about how to manage the objectives. And evaluating the control systems of the three versions offered by different manufacturers can be done at the same time.

As mentioned before, some main components for the control system will be listed and chosen from different suppliers. The main suppliers selected for comparison on control system main components are:
Phoenix Contact; www.Phoenixcontact.com
Wago; www.wago.com, and
Omron (Japanese). www.omron.com

By doing comparing work based on the components lists and requirements, the comparisons of commercial offers for the control system components of the three versions can be seen from *Table 6.1*, *6.2* and *6.3*.

With the comparison of them, obviously, the Phoenix Contact is the best choice because of the cheapest price, less components, good quality and good technical support.

Table 6.1 The comparison table of the control system components from different suppliers for Version 1

	Wago	Quantity	Price	Total price	Phoenix/Bluetooth	Quantity	Price	Total price	Omron	Quantity	Price	Total price
Control cabinet												
PLC	750-841	1	#	#	ILC 130 ETH 8 inputs, 4 outputs	1	#	#	CJ1W-CPU11-NL 16 I/O	1	#	#
Input digital	750-430 8ch	4	#	#	IB IL 24 DI 32/HD-PAC 32ch 1wire	1	#	#	CJ1W-ID211 CHN 16ch	2	#	#
Output digital	750-530 8ch	2	#	#	IB IL 24 DO 32/HD-PAC 32ch 1wire	1	#	#	CJ1W-OD212 CHN 1*16ch	1	#	#
Software	Free	1	#	#	PC WORX Demo	1	#	#				
Power Supply	787-722	1	#	#	STEP-PS/1AC/24DC/4.2	1	#	#	CJ1W-PD022 (21.6-26.4 VDC)	1	#	#
Costs				#				#				#
Vehicle												
EthernetCoupler	750-342	1	#	#	ILB ETH 24 32inputs,16outputs	1	#	#	CP1L-M30DT1-D	1		#
Input digital	750-402 4ch 3wire	4	#	#					GRT1-ID4-1 3wire4ch	4	#	#
Output digital	750-531 4ch 2wire	2	#	#					GRT1-OD4G-1 3wire4ch	2	#	#
Costs				#				#				#
Total costs				865,8				530				1150

Table 6.2 The comparison table of the control system components from different suppliers for Version 2

	Wago	Quantity	Price	Total price	Phoenix/Bluetooth	Quantity	Price	Total price	Omron	Quantity	price	Total price
Control cabinet												
PLC	750-841	1	#	#	ILC 130 ETH 8 inputs, 4 outputs	1	#	#	CJ1W-CPU11-NL	1	#	#
Input digital	750-430 8ch	4	#	#	IB IL 24 DI 32/HD-PAC 32ch 1wire	1	#	#	CJ1W-ID211 CHN 16ch	2	#	#
Output digital	750-530 8ch	2	#	#	IB IL 24 DO 32/HD-PAC 32ch 1wire	1	#	#	CJ1W-OD212 CHN 1*16ch	1	#	#
Wireless	PhoenixC-2692791 FL WLAN EPA	1	#	#	FL BLUETOOTH AP	1	#	#	PhoenixC-2692791 FL WLAN EPA	1	#	#
Power Supply	787-722	1	#	#	STEP-PS/1AC/24DC/4.2	1	#	#	CJ1W-PD022 (21.6-26.4	1	#	#
Costs				#				#				#
Vehicle												
(PLC)	750-342	1	#	#	ILB BT ADIO 2/2/16/1	1	#	#	CP1L-M30DT1-D	1	#	#
Input digital	750-402 4ch 3wire	4	#	#					GRT1-ID4-1 3wire4ch	4	#	#
Output digital	750-531 4ch 2wire	2	#	#					GRT1-OD4G-1 3wire4ch	2	#	#
Wireless	PhoenixC-2692791 FL WLAN EPA	1	#	#	FL BLUETOOTH AP	1	#	#	PhoenixC-2692791 FL WLAN EPA	1	#	#
Costs				#				#				#
Total costs				1285,5				840,24				1827,42

Table 6.3 The comparison table of the control system components from different suppliers for Version 3

	Wago	Quantity	Price	Total price	Phoenix/Bluetooth	Quantity	Price	Total price	Omron	Quantity	Price	Total price
Control cabinet												
PLC	750-841	1	#	#	ILC 130 ETH 8inputs,4outputs	1	#	#	CJ1W-CPU22 NL	1	#	#
Input digital	750-430 8ch	4	#	#	IB IL 24 DI 32/HD-PAC 32ch 1wire	1	#	#	CJ1W-ID211 CHN 16ch	2	#	#
Output digital	750-530 8ch	2	#	#	IB IL 24 DO 32/HD-PAC 32ch 1wire	1	#	#	CJ1W-OD212 CHN 1*16ch	1	#	#
Input analog	753-456 2ch	1	#	#	IB IL AI 2/SF-PAC	1	#	#	GRT1-AD2 2ch	1	#	#
Wireless	IE-WLAN-BRIDGE-WAVE	1	#	#	FL BLUETOOTH AP	1	#	#	PhoenixC-2692791 FL WLAN EPA	1	#	#
Software	Free	1	#	#	PC WORX Demo	1	#	#				
Power Supply	787-722	1	#	#	STEP-PS/1AC/24DC/4.2	1	#	#				
Costs				#				#				#
Vehicle												
(PLC)	750-342	1	#	#	ILC 130 ETH 8inputs,4outputs	1	#	#	CJ1W-CPU22 NL	1	#	#
Input digital	750-402 4ch3wire	4	#	#	IB IL 24 DI 4-PAC 4ch 3wire	2	#	#	GRT1-ID4-1 3wire4ch	4	#	#
Output digital	750-531 4ch2wire	2	#	#	IB IL 24 DO 4-PAC 4ch 3wire	1	#	#	GRT1-OD4G-1 3wire4ch	2	#	#
Output analog	750-550 2ch	1	#	#	IB IL AO 2/U/BP-PAC	1	#	#	GRT1-DA2V 2ch	1	#	#
Wireless	IE-WLAN-BRIDGE-WAVE	1	#	#	FL BLUETOOTH AP	1	#	#	PhoenixC-2692791 FL WLAN EPA	1	#	#
DC-Drive Controller	750-636 1ch	2	#	#	IB IL DC AR 48/10A	2	#	#	CJ1W-DCM11-E	2	#	#
Costs				#				#				#
Total Costs				2397,66				1650,23				2063,90

7 DESCRIPTION OF REAL CONTROL SYSTEM UNITS AND COMPONENTS

7.1 PLC COMPONENTS

7.1.1 ILC 130 ETH

The **ILC130ETH** Inline controller can be used as a distributed control system of an Inline station, which is connected to an Ethernet system. An Inline local bus (*Figure7.1*) can then be connected to the Inline controller. But the ILC 130 ETH does not support connection of the INTERBUS remote bus.

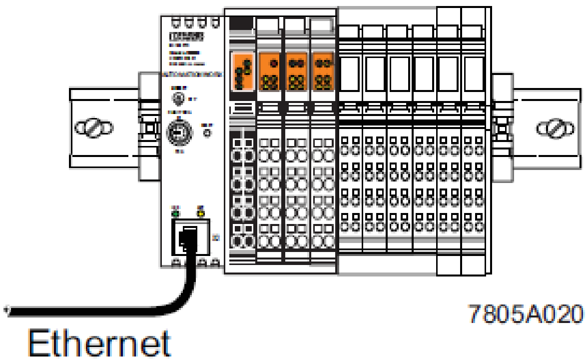


FIGURE 7.1 Connected Inline local bus /16/

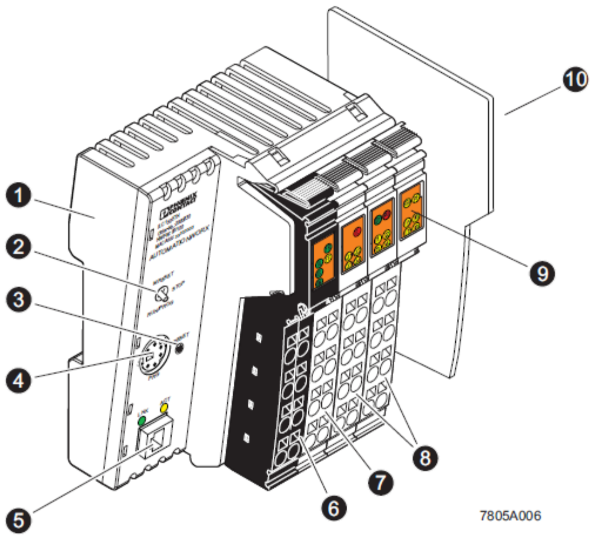


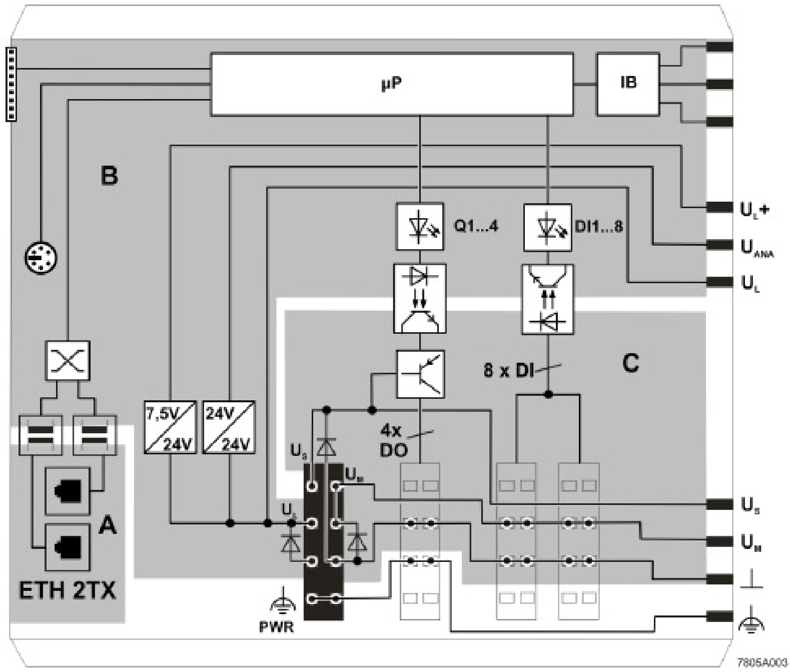
FIGURE 7.2 Structure of the Inline controller (ILC 130 ETH) /16/

The Inline controller (ILC 130 ETH) (*Figure 7.2*) consists of the following components:

1 Electronics base
2 Mode selector switch
3 Reset button
4 V.24 (RS-232) interface
5 Ethernet connection

6 Connector 1: Terminal points for voltage supply
7 Connector 2: Output terminal point
8 Connectors 3 and 4: Input terminal points
9 Diagnostic and status indicators
10 End plate

The figure below shows the internal basic circuit diagram of ILC 170 ETH 2TX which belongs to the same family and is similar with ILC 130 ETH. It is easy to find that all the U_S, U_M and GND are connected together within all the connectors.



Key:

- Microprocessor
- Protocol chip
- V. 24 (RS-232) interface
- Transmitter
- RJ45 female connector
- SD card holder (the SD card is not supplied as standard)
- Converters
- LED
- Optocoupler
- NPN transistor
- Ethernet switch

FIGURE 7.3 Internal basic circuit diagram (ILC 170 ETH 2TX) /16/

The gray areas in the basic circuit diagram represent the electrically isolated areas.
A: Ethernet interface
B: Logic
C: I/O

Supply the Inline controller using external 24 V DC voltage sources. The permissible voltage ranges from 19.2 V DC to 30 V DC (ripple included). The power consumption of the Inline controller at 24 V is typically 4.8 W (no local bus devices connected). For making sure the circuit is safety and connected with the PE, one terminal of N (GND) can connect with the PE. *Table 7.1* gives the list of terminal point of power supply in the ILC 130 ETH.

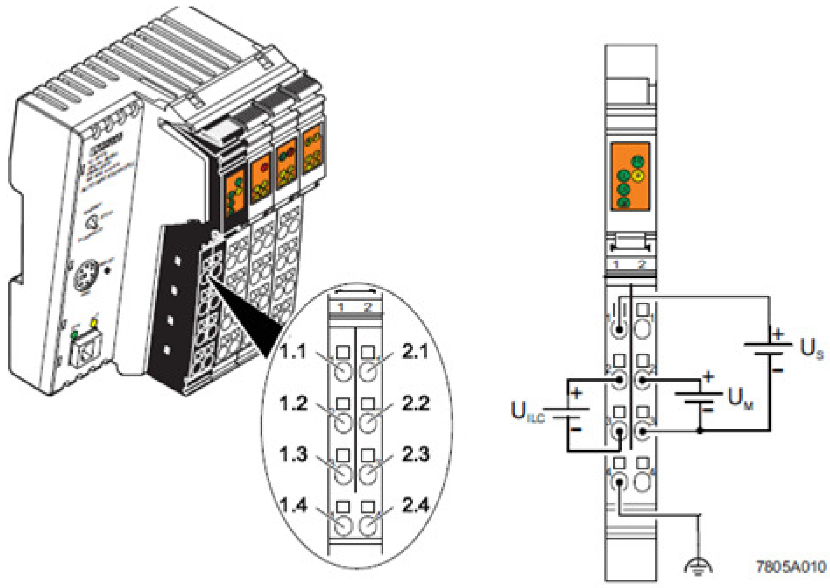


FIGURE 7.4 Supply voltage connection of ILC 130 ETH. /16/

Table 7.1 Terminal point of power supply /16/

Terminal point	**Assignment**		**Comment**
Connector 1	**Power connector**		
1.1	24 V DC (US)	24 V segment voltage supply	The supplied voltage is directly routed to the potential jumper.
1.2	24 V DC (UILC)	24 V supply	The 7.5 V communications power (UL) for the ILC and the connected local bus devices is generated from this voltage. The 24 V analog power (UANA) for the local bus devices is also generated.
2.1,2.2	24 V DC (UM)	24 V main voltage supply	The main voltage is routed to the local bus devices via the potential jumpers.
1.3	LGND	Reference potential logic ground	The potential is reference ground for the communications power.
2.3	SGND	Reference potential segment ground	The reference potential is directly led to the potential jumper and is, at the same time, reference ground for the main and segment supply.
1.4,2.4	FE	Functional earth ground (FE)	Functional earth ground must be connected through the power supply.

The following figure gives an assignment of all the terminal points of the connectors 2 to 4 in this PLC which is explained in detail from *Table 7.2*.

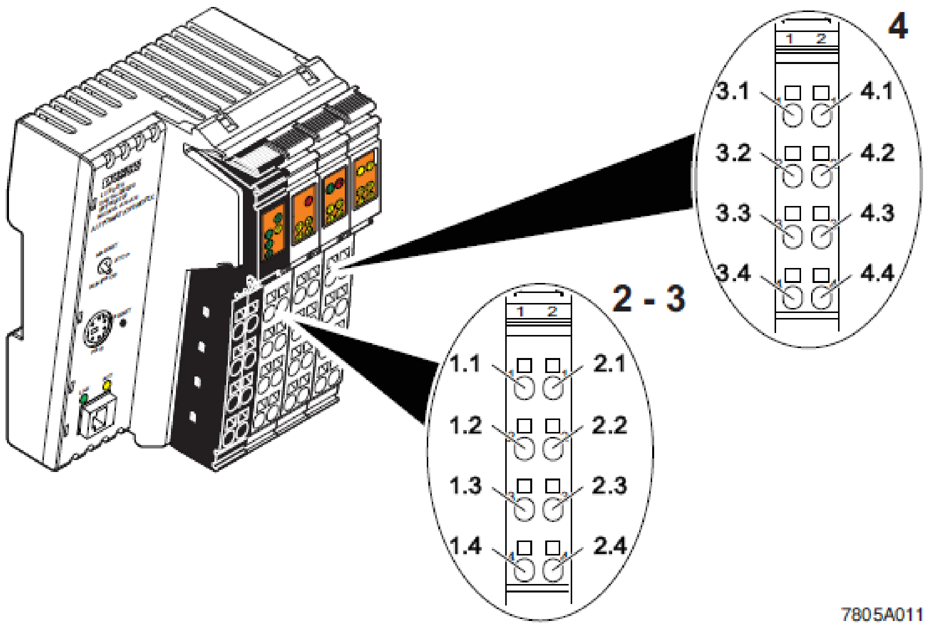


FIGURE 7.5 Assignment of the terminal points of connectors 2 to 4. /16/

Table 7.2 Terminal point assignment of inputs/outputs /16/

Terminal point	**Assignment**	**Comment**
Connector 2	**Output terminal points**	
1.1	Q1	Output 1
2.1	Q2	Output 2
1.2,2.2	GND	Ground contact for 2 and 3-wire termination
1.3,2.3	FE	Functional earth ground 3-wire termination
1.4	Q3	Output 3
2.4	Q4	Output 4
The outputs are supplied with 24 V DC from the segment supply (US).		
Connector 3	Input terminal points	
1.1	I1	Input 1
2.1	I2	Input 2
1.2,2.2	24 V	Supply voltage UM for 2 and 3-wire termination
1.3,2.3	GND	Ground contact for 3-wire termination
1.4	I3	Input 3
2.4	I4	Input 4
Connector 4	Input terminal points	
3.1	I5	Input 5
4.1	I6	Input 6
3.2,4.2	24 V	Supply voltage UM for 2 and 3-wire termination
3.3,4.3	GND	Ground contact for 3-wire termination
3.4	I7	Input 7
4.4	I8	Input 8
The inputs are supplied with 24 V DC from the main supply (UM).		

7.1.2 ILB ETH 24 DI16 DIO16-2TX

The ILB ETH 24 DI16 DIO16-2TX module is designed for use within an Ethernet network. It is used to acquire and output digital signals.

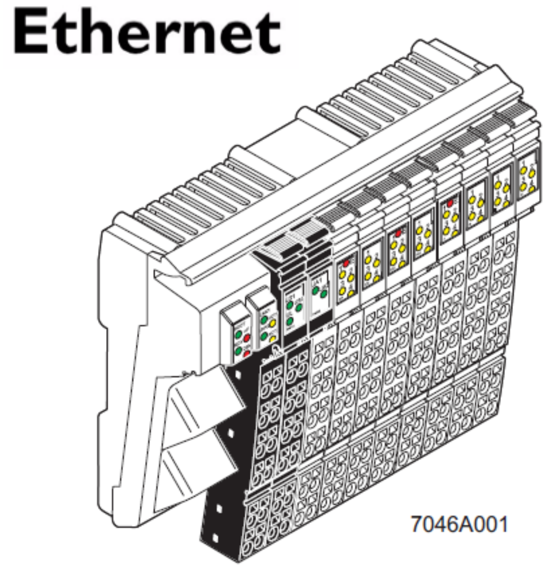


FIGURE 7.6 Model of ILB ETH 24 DI 16 DIO16-2TX. /17/

The input features for this Inline Block IO Module are:
– Connections for 16 digital sensors
– Connection of sensors in 2 and 3-wire technology
– Maximum permissible load current per sensor: 125 mA
– Maximum permissible load current from the sensor supply: 2.0 A

Combined Input and Output Features for this Inline Block IO Module are:
– Connections for 16 digital sensors/actuators
– Each single channel can only be used as an input or as an output
– Connection of sensors in 2 and 3-wire technology
– Maximum permissible load current per sensor: 125 mA
– Maximum permissible load current from the sensor supply: 2.0 A
– Connection of actuators in 2-wire technology
– Nominal current per output: 0.5 A
– Total current of all outputs: 8 A
– Short-circuit and overload protected outputs

The figure below shows the internal basic circuit diagram of this Ethernet couple. The power supply for the digital output and digital input/output are separated into U_{S1} and U_{S2}. The connection between this Ethernet couple and the main PLC goes through the 2TX ETH point by a cable.

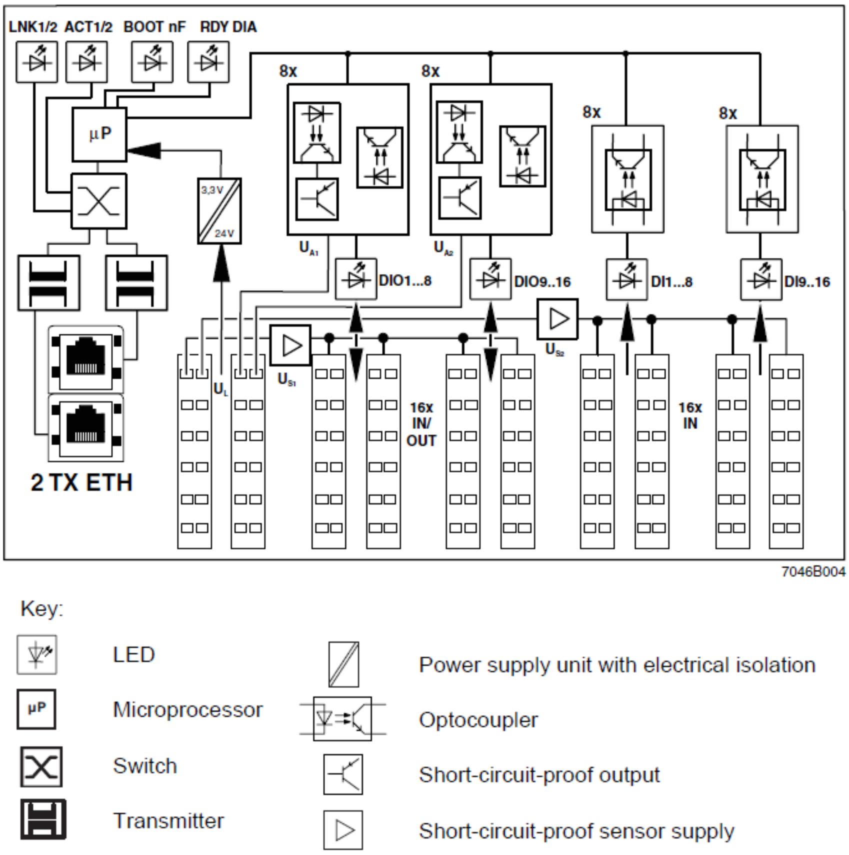


FIGURE 7.7 Internal wiring of the terminal points. /17/

The figure below shows terminal point assignment of the Inline connectors. The wiring connection between the electrical component and this Ethernet coupler is explicit by combining this figure with *Table 7.3*, *7.4* and *7.5*.

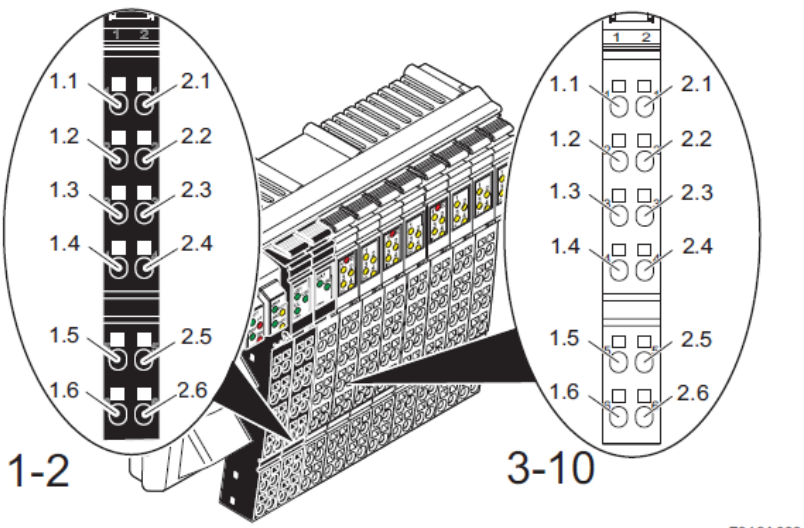


FIGURE 7.8 Terminal point assignments of the Inline connectors. /17/

Table 7.3 Terminal Point Assignment of the Power Connectors /17/

Terminal Point	Assignment	Terminal Point	Assignment
Connector 1 (PWR 1)			
1.1	24 V sensor supply U_{S1}	**2.1**	24 V sensor supply U_{S2}
1.2	24 V communications power U_L	**2.2**	24 V communications power U_L
1.3	GND	**2.3**	GND
1.4	FE	**2.4**	FE
1.5	24 V communications power U_L	**2.5**	24 V communications power U_L
1.6	GND	**2.6**	GND
Connector 2 (PWR 2)			
1.1	Actuator supply U_{A1}	**2.1**	Actuator supply U_{A2}
1.2	24 V communications power U_L	**2.2**	24 V communications power U_L
1.3	GND	**2.3**	GND
1.4	FE	**2.4**	FE
1.5	24 V communications power U_L	**2.5**	24 V communications power U_L
1.6	GND	**2.6**	GND

Table 7.4 Terminal Point Assignment of the Input and Output Connectors /17/

Terminal Point				Assignment
Connector 3 (IO1)	**Connector 4 (IO2)**	**Connector 5 (IO3)**	**Connector 6 (IO4)**	
1.1, 2.1	**1.1, 2.1**	**1.1, 2.1**	**1.1, 2.1**	Signal input (IN) and output (OUT)
1.2, 2.2	**1.2, 2.2**	**1.2, 2.2**	**1.2, 2.2**	Sensor voltage U_{I1} for 2 and 3-wire termination
1.3, 2.3	**1.3, 2.3**	**1.3, 2.3**	**1.3, 2.3**	Ground contact (GND) for 3-wire termination
1.4, 2.4	**1.4, 2.4**	**1.4, 2.4**	**1.4, 2.4**	Signal input (IN) and output (OUT)
1.5, 2.5	**1.5, 2.5**	**1.5, 2.5**	**1.5, 2.5**	Initiator supply U_{I1} for 2 and 3-wire termination
1.6, 2.6	**1.6, 2.6**	**1.6, 2.6**	**1.6, 2.6**	Ground contact (GND) for 3-wire termination

Table 7.5 Terminal Point Assignment of the Input Connectors /17/

Terminal Point				Assignment
Connector 7 (I1)	**Connector 8 (I2)**	**Connector 9 (I3)**	**Connector 10 (I4)**	
1.1, 2.1	**1.1, 2.1**	**1.1, 2.1**	**1.1, 2.1**	Signal input (IN)
1.2, 2.2	**1.2, 2.2**	**1.2, 2.2**	**1.2, 2.2**	Sensor voltage U_{IS} for 2 and 3-wire termination
1.3, 2.3	**1.3, 2.3**	**1.3, 2.3**	**1.3, 2.3**	Ground contact (GND) for 3-wire termination
1.4, 2.4	**1.4, 2.4**	**1.4, 2.4**	**1.4, 2.4**	Signal input (IN)
1.5, 2.5	**1.5, 2.5**	**1.5, 2.5**	**1.5, 2.5**	Initiator supply U_{I2} for 2 and 3-wire termination
1.6, 2.6	**1.6, 2.6**	**1.6, 2.6**	**1.6, 2.6**	Ground contact (GND) for 3-wire termination

The figure below shows a connection example of this unit.

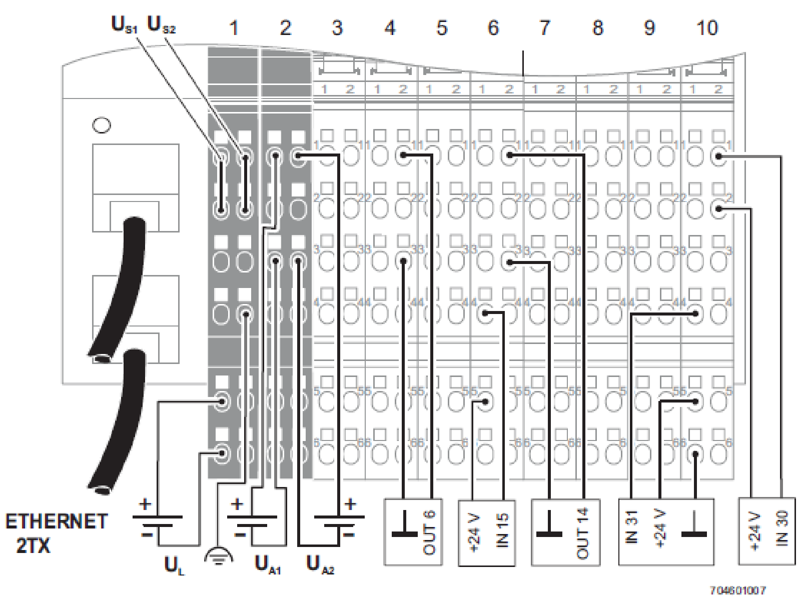


FIGURE 7.9 Connection example of this Inline Block IO Module. /17/

7.1.3 IB IL 24 DI/DO 32/HD-PAC

IB IL 24 DI 32/HD-PAC is the inline terminal with 32 digital inputs. This terminal is designed for use within an Inline station. It is used to acquire digital input signals. The features of it are:
–Connections for 32 digital sensors
–Connection of sensors in single-wire technology
–Diagnostic and status indicators
–IB IL 24 DI 32/HD-PAC, IB IL 24 DI 32/HD:
Approved for use in potentially explosive areas

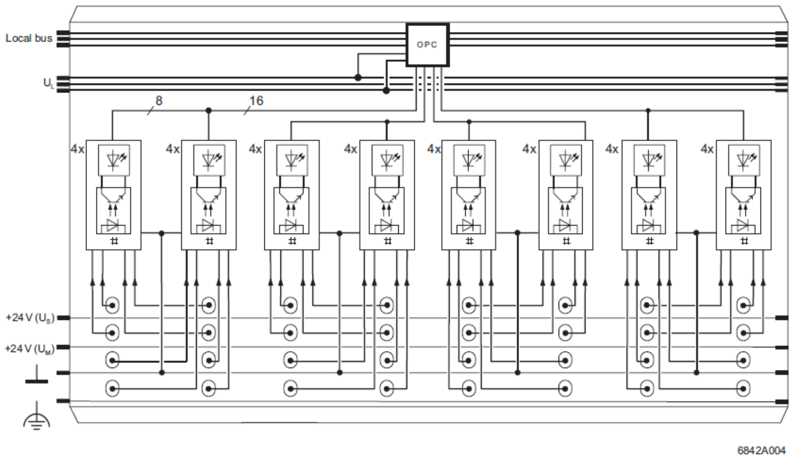


FIGURE 7.10 Internal wiring of the terminal points /18/

As Figure 7.11 shows, there is no segment voltage supplier for each terminal point. Therefore, each point needs an extra terminal to supply the segment voltage. The corresponding assignment for each terminal point can be seen from *Table 7.6*.

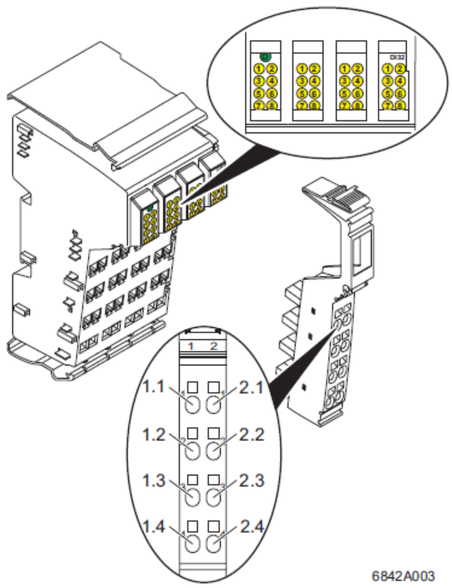


FIGURE 7.11 Terminal with one of the appropriate connectors. /18/

Table 7.6 Terminal Point Assignment of IB IL 24 DI 32/HD-PAC /18/

Terminal point	Assignment
1.1 / 2.1	Signal input (IN 1/IN 2)
1.2 / 2.2	Signal input (IN 3/IN 4)
1.3 / 2.3	Signal input (IN 5/IN 6)
1.4 / 2.4	Signal input (IN 7/IN 8)
3.1 / 4.1	Signal input (IN 9/IN 10)
3.2 / 4.2	Signal input (IN 11/IN 12)
3.3 / 4.3	Signal input (IN 13/IN 14)
3.4 / 4.4	Signal input (IN 15/IN 16)
5.1 / 6.1	Signal input (IN 17/IN 18)
5.2 / 6.2	Signal input (IN 19/IN 20)
5.3 / 6.3	Signal input (IN 21/IN 22)
5.4 / 6.4	Signal input (IN 23/IN 24)
7.1 / 8.1	Signal input (IN 25/IN 26)
7.2 / 8.2	Signal input (IN 27/IN 28)
7.3 / 8.3	Signal input (IN 29/IN 30)
7.4 / 8.4	Signal input (IN 31/IN 32)

IB IL 24 DO 32/HD-PAC has the same feature and layout, and similar internal circuit diagram with IB IL 24 DO 32/HD-PAC, the only difference is the terminal point assignment. The terminal point assignment of IB IL 24 DO 32/HD-PAC can get by changing the name “signal input” to “signal output”.

7.1.4 IB IL 24 DI/DO 4-PAC

IB IL 24 DI 4-PAC is an inline terminal with 4 digital inputs. It is designed for use within an Inline station. It is used to acquire digital input signals. The features of this terminal are:
– Connections for four digital sensors
– Connection of sensors in 2 and 3-wire technology
– Maximum permissible load current per sensor: 250 mA
– Maximum permissible load current from the terminal: 1.0 A
– Diagnostic and status indicators
– Approved for the use in potentially explosive areas

Combining the terminal with appropriate points in *Figure 7.12* and the terminal point assignment in *Table 7.7* can easily make the wiring connection to each input.

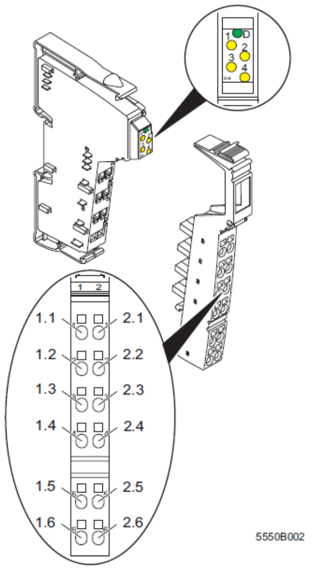


FIGURE 7.12 Terminal with appropriate connector. /19/

Table 7.7 Terminal point assignment for IB IL 24 DI 4-PAC /19/

Terminal point	Assignment
1.1	Signal input 1 (IN 1)
2.1	Signal input 2 (IN 2)
1.2, 2.2	Segment voltage U_S for 2 and 3-wire termination
1.3, 2.3	Ground contact (GND) for 3-wire termination
1.4	Signal input 3 (IN 3)
2.4	Signal input 4 (IN 4)
1.5, 2.5	Segment voltage U_S for 2 and 3-wire termination
1.6, 2.6	Ground contact (GND) for 3-wire termination

IB IL 24 DO 4-PAC has the same feature and layout, and similar internal circuit diagram with IB IL 24 DI 4-PAC, the only difference is the terminal point assignment. The terminal point assignment for this digital output terminal is shown in *Table 7.8*.

Table 7.8 Terminal point assignment for IB IL 24 DO 4-PAC /20/

Terminal Point	Assignment
1.1	Signal output (OUT 1)
2.1	Signal output (OUT 2)
1.2, 2.2	Ground contact (GND) for 2 and 3-wire termination
1.3, 2.3	FE connection for 3-wire termination
1.4	Signal output (OUT 3)
2.4	Signal output (OUT 4)
1.5, 2.5	Ground contact (GND) for 2 and 3-wire termination
1.6, 2.6	FE connection for 3-wire termination

7.1.5 IB IL AI 2/4-20-PAC

This terminal is an INTERBUS inline terminal with two analog input channels. It is designed for use within an INTERBUS Inline station. It is used to measure analog voltage or current signals. (*Figure 7.14*) The voltage supply U_S U_M GND and FE are connected together which are giving from the main PLC (*Figure 7.13*).

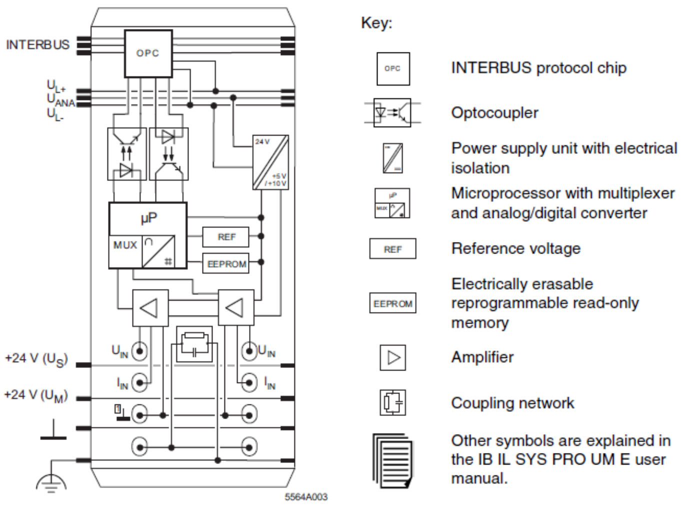


FIGURE 7.13 Internal wiring of the terminal points. /21/

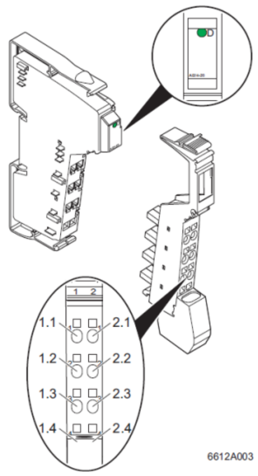


FIGURE 7.14 IB IL AI 2/4-20 terminals with the appropriate connector. /21/

Table 7.9 Terminal point assignment of this analog inputs terminal /21/

Terminal Points	Signal	Assignment
1.1	+U1	Voltage input channel 1
2.1	+U2	Voltage input channel 2
1.2	+I1	Current input channel 1
2.2	+I2	Current input channel 2
1.3	-1	Return for channel 1 (common for current and voltage)
2.3	-2	Return for channel 2 (common for current and voltage)
1.4, 2.4	Shield	Shield connection

Notice to create a separate main circuit for each analog terminal. If this is not possible in the application and the analog terminals are used in a main circuit together with other terminals, place the analog terminals behind all the other terminals at the end of the main circuit.

7.1.6 IB IL 24 DI 16-PAC

IB IL 24 DI 16-PAC is an inline terminal with 16 digital inputs. The terminal is designed for use within an Inline station. It is used to acquire digital signals. The features of this unit are:
– Connections for 16 digital sensors
– Connection of sensors in 2 and 3-wire technology
– Maximum permissible load current per sensor: 250 mA
– Maximum permissible load current from the terminal: 4.0 A
– Diagnostic and status indicators
– Approved for use in potentially explosive areas

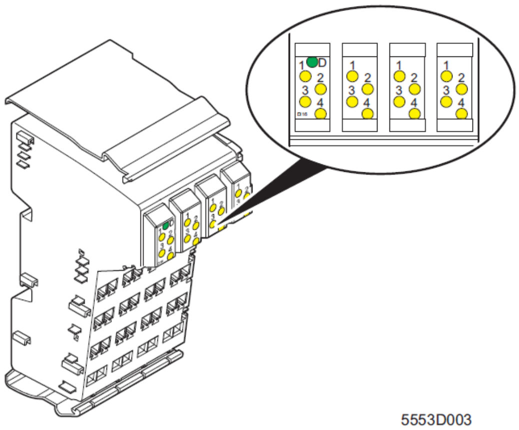


FIGURE 7.15 Local diagnostic and status indicators. /22/

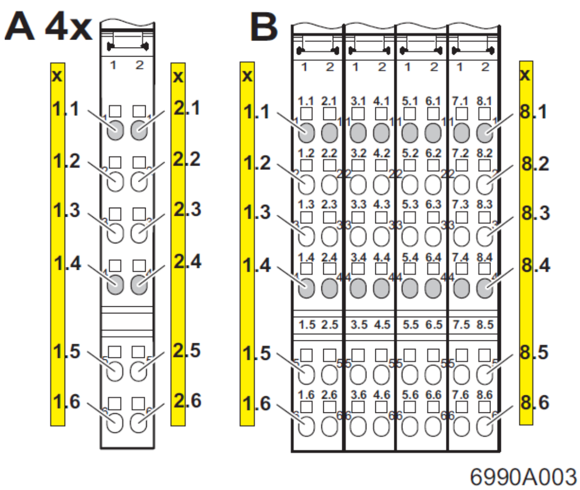


FIGURE 7.16 Terminal point numbering: individual connectors (**A**) and connector sets (**B**) /22/

A – Using the IB IL 24 DI 16-PAC/SN and
IB IL 24 DI 16-2MBD-PAC/SN with the connectors provided
– Using individual connectors (IB IL SCN-12 or IB IL SCN-12-ICP)

B – Using the IB IL 24 DI 16-PAC and IB IL 24 DI 16-2MBD-PAC with the original connector set
– Using the IB IL 24 DI 16-PLSET/ICP or IB IL DI/DO 16-PLSET connector sets

As the unit used is IB IL 24 DI 16-PAC, it should use the original connector sets. The circuit and wiring connection can be made by combining the *table 7.10*.

Table 7.10 Terminal point assignment of this digital input unit with 16 points /22/

Terminal Point	Assignment
x.1	Signal input (IN)
x.2	Segment voltage U_S for 2 and 3-wire termination
x.3	Ground contact (GND) for 3-wire termination
x.4	Signal input (IN)
x.5	Segment voltage U_S for 2 and 3-wire termination
x.6	Ground contact (GND) for 3-wire termination

7.1.7 IB IL 24 DO 8-PAC

IB IL 24 DO 8-PAC (*Figure 7.17*) is an inline terminal with eight digital outputs. The terminal is designed for use within an Inline station. It is used to output digital signals. The features of this unit are:
– Connections for eight digital actuators
– Connection of actuators in 2, 3, and 4-wire technology
– Nominal current of each output: 0.5 A
– Total current of the terminal: 4 A
– Short-circuit and overload protected outputs
– Diagnostic and status indicators
– Approved for use within a safety-related segment circuit

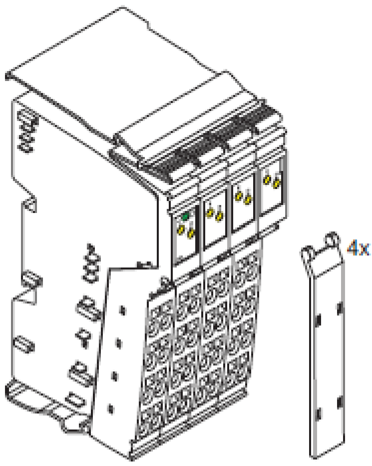


FIGURE 7.17 Inline Terminals with eight digital outputs. /23/

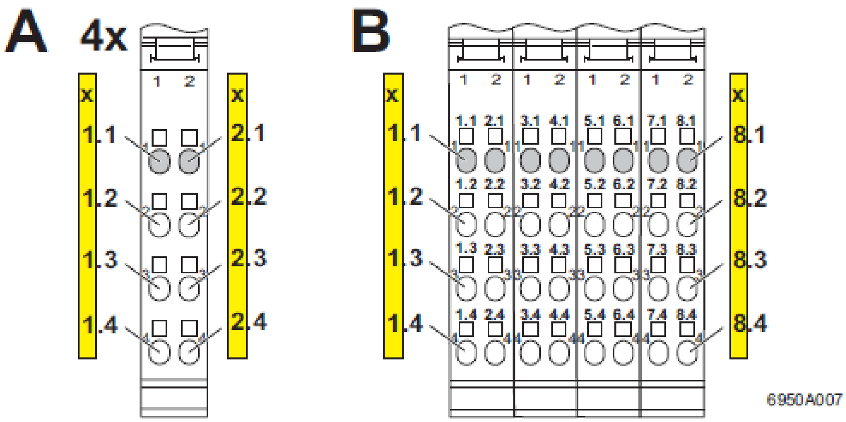


FIGURE 7.18 Terminal point numbering: individual connectors **(A)** and connector sets **(B)** /23/

A – Using the IB IL 24 DO 8-PAC/SN or IB IL 24 DO 8-2MBD-PAC/SN with the supplied connectors
– Using individual connectors (IB IL SCN-8 or IB IL SCN-8-CP)

B – Using the IB IL 24 DO 8-PAC or IB IL 24 DO 8-2MBD-PAC with the original connector set
– Using a connector set (IB IL DI/DO 8-PLSET or IB IL DI/DO 8-PLSET/CP)

As the hiring unit is IB IL 24 DO 8-PAC, the original connector set (B) is used. Combining with *Table 7.11*, the circuit and wiring connection can be made.

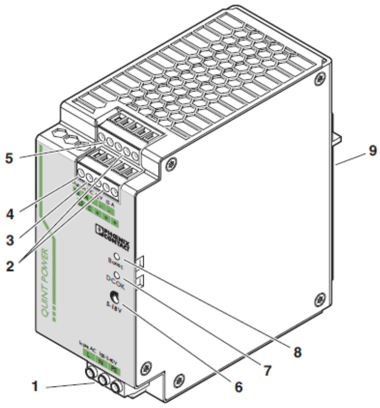
Table 7.11 Terminal point assignment of IB IL 24 DO 8-PAC /23/

Terminal Point	Assignment
x.1	Signal output (OUT 1)
x.2	Segment voltage U_S for 4-wire termination Measuring points for the supply voltage
x.3	Ground contact (GND) for 2, 3, and 4-wire termination
x.4	FE connection for 3 and 4-wire termination

7.2 POWER SUPPLY

7.2.1 QUINT-PS/1AC/12DC/15

QUINT-PS/1AC/12DC/15 is the DIN rail power supply unit with 12 V DC/15 A. It is a 1-phase primary switched-mode. The SFB technology (Selective Fuse Breaking Technology) can now also be used to trigger standard power circuit breakers reliably and quickly. (*Figure 7.19*)



1 AC input
2 DC output
3 POWER BOOST switching output, active
4 DC OK switching output active
5 DC OK output, floating
6 Potentiometer 5 V DC ... 18 V DC
7 "DC OK" LED
8 "BOOST" LED
9 Universal DIN rail adapter UTA 107/30

	[mm^2] solid	[mm^2] stranded	AWG	[Nm] Torque
Input	0.2 - 2.5	0.2 - 2.5	16 - 12	0.5 - 0.6
Output	0.2 - 2.5	0.2 - 2.5	16 - 12	0.5 - 0.6
Signal	0.2 - 2.5	0.2 - 2.5	16 - 12	0.5 - 0.6

FIGURE 7.19 Structure of QUINT-PS/1AC/12DC/15. /24/

The block diagram of this power supply can be seen from *Figure 7.20*. The voltage between the terminal point “+” and “-” is 12 V DC which is supplying the power of motors. And the power supply for this unit is 230 V AC.

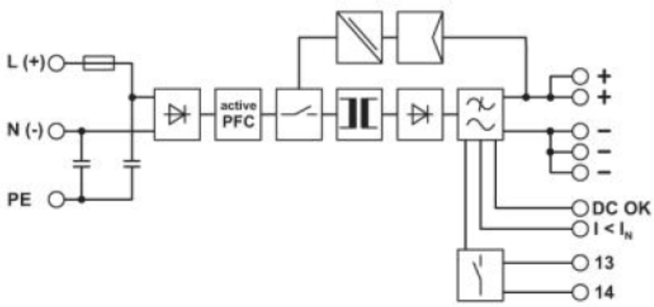
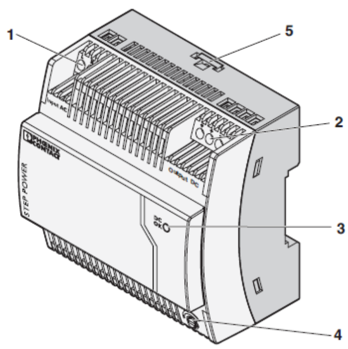


FIGURE 7.20 Block diagram of QUINT-PS/1AC/12DC/15. /24/

7.2.2 STEP-PS/1AC/24DC/4.2

STEP-PS/1AC/24DC/4.2 is a DIN rail power supply unit with 24 V DC/4.2 A (*Figure 7.21*). It is a 1-phase primary switched-mode. It is used to supply the power to PLCs and other electrical components using in the control system. The block diagram can be seen in Figure 7.22. The power supply for this unit is 230 V AC.



1 AC input
2 DC output
3 "DC OK" LED
4 Potentiometer 22.5 V DC ... 29.5 V DC
5 Universal snap-on foot for EN DIN rails and for wall mounting

	[mm^2] solid	[mm^2] stranded	AWG	[Nm] Torque
Input	0.2 - 2.5	0.2 - 2.5	24 - 12	0.6 - 0.8
Output	0.2 - 2.5	0.2 - 2.5	24 - 12	0.6 - 0.8

FIGURE 7.21 Structure of STEP-PS/1AC/24DC/4.2. /25/

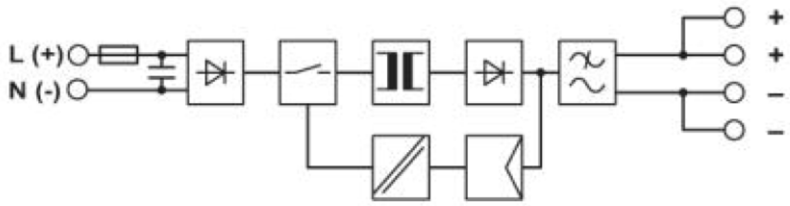


FIGURE 7.22 Block diagram of STEP-PS/1AC/24DC/4.2. /25/

7.3 IB IL DC AR 48/10A

The IB IL DC AR 48/10A of PHOENIX CONTACT is an inline servo amplifier for DC Motors with brushgears. The Inline servo amplifier is designed for use within an Inline station. It is a universal speed or torque controller with a power output module for permanently excited DC motors with brushgears with a power consumption of up to 450 W. The Inline servo amplifier has a 4 quadrant function, i.e., it supplies power back to the power supply unit when the brake function is used.

The Inline servo amplifier consists of the following components:
1 Motor connection
2 Power supply connection
3 Diagnostic and status indicators
4 Heatsink

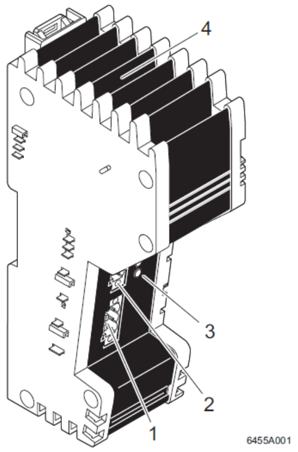


FIGURE 7.23 Structure of the Inline servo amplifier. /26/

The power connection in component 2 can be enlarged as *Figure 7.24*. The motor connection in component 1 can be enlarged as *Figure 7.25*.

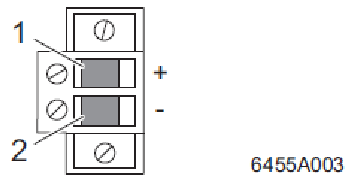


FIGURE 7.24 Terminal point assignment of the power supply connection (US). /26/

Table 7.12 Terminal point assignment of power supply /26/

Terminal Point	Assignment
1	U_S +
2	U_S –

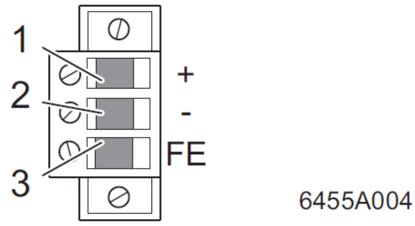


FIGURE 7.25 Terminal point assignment of the motor connection (MOTOR). /26/

Table 7.13 Terminal point assignment of motor /26/

Terminal Point	Assignment
1	Motor +
2	Motor –
3	Functional earth ground (FE)

7.4 PR2-RSC3-LDP-24DC/2X21

PR2-RSC3-LDP-24DC/2X21 is a preassembled relay module with screw connection, consisting of: Relay socket, industrial relay with integrated LED, free-wheeling diode and engage/disengage manual actuate lever, and retaining bracket. Input voltage: 24 V DC, two PDTs, 10 A.

The figure below is the circuit diagram of this relay.

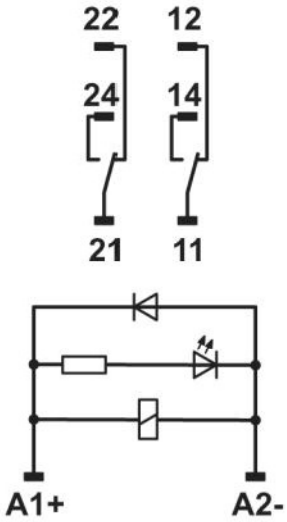


FIGURE 7.26 Circuit diagram of PR2-RSC3-LDP-24DC-2X21. /27/

8 CONTROL SYSTEM CIRCUIT AND WIRING DESIGN

8.1 CONTROL SYSTEM CIRCUIT AND WIRING DESIGN FOR VERSION 1

In version 1, all the used units and components can be list as follow:

Table 8.1 Units and components used in the control system for version 1.

Name	**Quantity**	**Location**	**Description**
ILB 130 ETH	1	Control cabinet	PLC
IB IL 24 DI 16-PAC	1	Control cabinet	Extra digital inputs
IB IL 24 DO 8-PAC	1	Control cabinet	Extra digital outputs
STEP-PS/1AC/24DC/4.2	1	Control cabinet	24 V power supply for PLC and other electrical components
PR2-RSC3-LDP-24DC/2X21	1	Control cabinet	Relay
QUINT-PS/1AC/12DC/15	1	Control cabinet	12 V power supply for motors
ILB ETH 24 DI16 DIO16-2TX	1	Vehicle	Inline connector to PLC with Ethernet
Motor	3	Vehicle	Running and lifting vehicle
PR2-RSC3-LDP-24DC/2X21	4	Vehicle	Relay
	4	Vehicle	Inductive sensor
	4	Vehicle	Limit switch
Motor	1	Warehouse	Motor for putting freights into cassette

Depending on the table above and the properties of each component, the circuit and wiring diagram can be designed shown in *Appendix 1*.
(The marking diagram for each terminal in PLCs for version 1 is shown in *Appendix 2*)

8.2 CONTROL SYSTEM CIRCUIT AND WIRING DESIGN FOR VERSION 3

In version 3, all the used units and components can be list as follow:

Table 8.2 Units and components used in the control system for version 3.

Name	**Quantity**	**Location**	**Description**
ILB 130 ETH	1	Control cabinet	PLC
IB IL 24 DI 32/HD-PAC	1	Control cabinet	Extra digital inputs
IB IL 24 DO 32/HD-PAC	1	Control cabinet	Extra digital outputs
IB IL AI 2/4-20-PAC	1	Control cabinet	Analog inputs
STEP-PS/1AC/24DC/4.2	1	Control cabinet	24 V power supply for PLC and other electri-cal components
QUINT-PS/1AC/12DC/15	1	Control cabinet	12 V power supply for motors
PR2-RSC3-LDP-24DC/2X21	1	Control cabinet	Relay for motor in warehouse
ILB 130 ETH	1	Vehicle	PLC
IB IL 24 DI 4-PAC	1	Vehicle	Extra digital inputs
IB IL 24 DO 4-PAC	1	Vehicle	Extra digital outputs
IB IL DC AR 48/10A	2	Vehicle	DC-Motor controller
Motor	3	Vehicle	Running and lifting vehicle
FL BLUETOOTH AP	1	Vehicle	Wireless connector
PR2-RSC3-LDP-24DC/2X21	2	Vehicle	Relay
	4	Vehicle	Inductive sensor
	4	Vehicle	Limit switch
Motor	1	Warehouse	Motor for putting freights into cassette

Depending on the table above and the properties of each component, the circuit and wiring diagram can be designed shown in *Appendix 3*.
(The marking diagram for each terminal in PLCs for version 3 is shown in *Appendix 4*)
The draft circuit and wiring connection with real components is *shown is Appendix 5*.

9 LAYOUT DESIGN FOR CONTROL SYSTEM CABINETS AND CONTROL PENDENT

9.1 LAYOUT DESIGN FOR CONTROL CABINET

9.1.1 LAYOUT DESIGN FOR CONTROL CABINET FOR VERSION 1

First of all, the thing needs to be clear is that all components for the control cabinet will be put into a box with size560mm×380mm×150mm shown in *Appendix 5*. Next step is to put all needed components in it and design a reasonable layout and leave the space of wiring also. In version 1, components need to be put into the control cabinet are:

Table 9.1 Components with size and quantity in the control cabinet for version 1

Name	**Quantity**	**Size(W×H×D)/mm**	**Description**
UT 2.5, UT 4-PE	9	5.2 ×47.7 ×47.5	Terminals for expanding the power supply from +230V AC.
QUIT-PS/1AC/12DC/15	1	60×130×125	Power supply +12V DC for motor
STEP-PS/1AC/24DC/4.2	1	90× 90×61	Power supply +24V DC for PLC and electrical components
ILC 130 ETH	1	80×119.8	PLC
IB IL 24 DI 16-PAC	1	48.8×140.5×71.5	Extra digital input
IB IL 24 DO 8-PAC	1	48.8×119.8×71.5	Extra digital output
PR2-RSC3-LDP-24DC/2X21	1	27 ×86 ×78.5	Relay for cutting power supply for the motor in warehouse
UK 6-FSI/C	3	8.2×64×52	Fuses for protecting the circuit of motors
UT 2,5, UT 4-PE	8	5.2 ×47.7 ×47.5	Terminals for expanding the power supply from +24V DC

According to the size and the quantity of each component, the layout of the control cabinet could be separated in two rows shown in *Figure 9.1*.

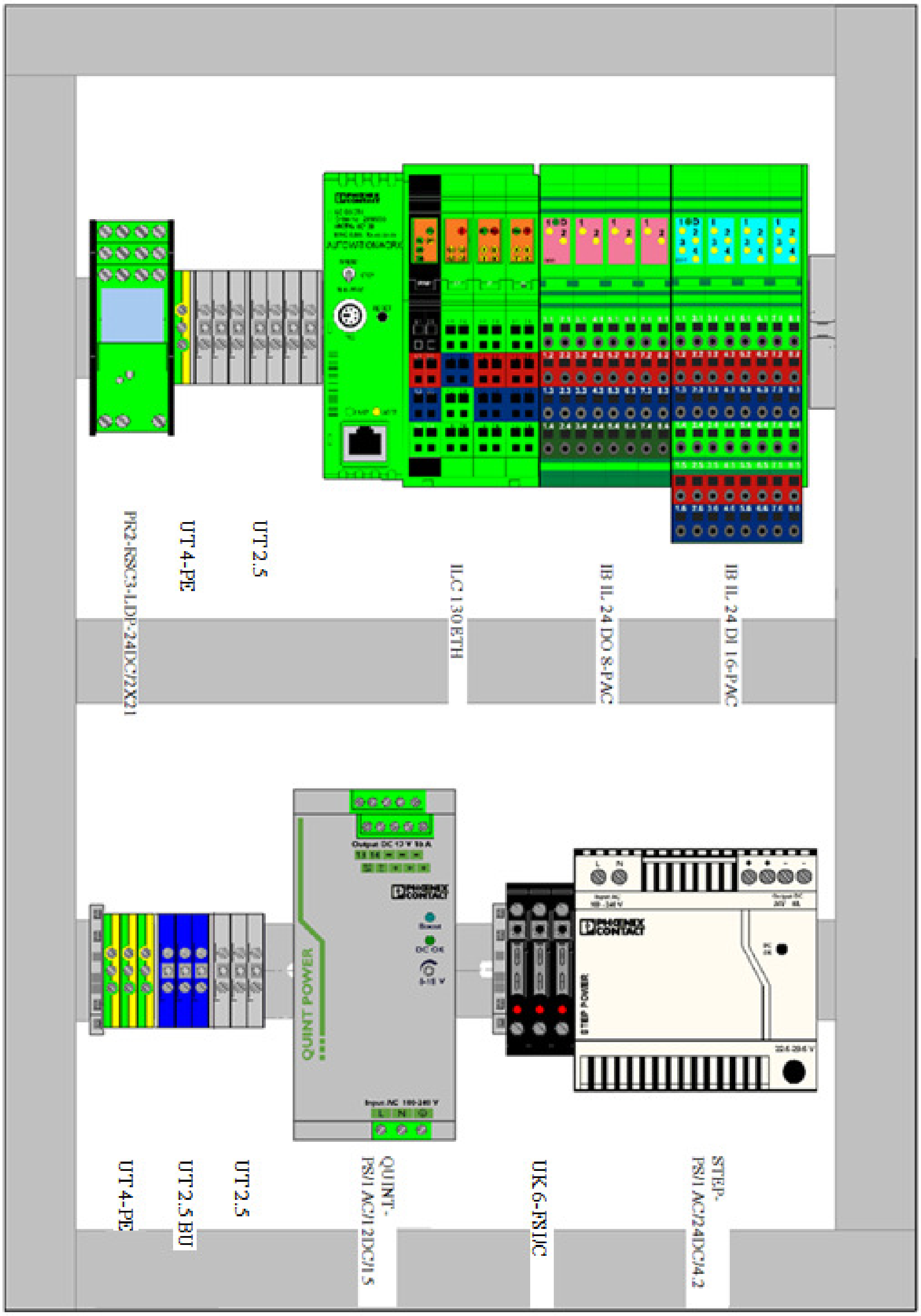


FIGURE 9.1 Layout of control cabinet for version 1.

9.1.2 LAYOUT DESIGN FOR CONROL CABINET FOR VERSION 3

First of all, the thing needs to be clear is that all components for the control cabinet will be put into a box with size 560mm×380mm×150mm shown in *Appendix 5*. Next step is to put all needed components in it and design a reasonable layout and leave the space of wiring also. In version 3, components need to be put into the control cabinet are:

Table 9.2 Components with size and quantity in the control cabinet for version 3

Name	**Quantity**	**Size(W × H × D)/mm**	**Description**
UT 2.5, UT 4-PE	9	5.2 ×47.7 ×47.5	Terminals for expanding the power supply from +230V AC.
QUIT-PS/1AC/12DC/15	1	60×130×125	Power supply +12V DC for motor
STEP-PS/1AC/24DC/4.2	1	90× 90×61	Power supply +24V DC for PLC and electrical components
ILC 130 ETH	1	80×119.8	PLC
IB IL 24 DI 32/HD-PAC	1	48.8×119.8×71.5	Extra digital input
IB IL 24 DO 32/HD-PAC	1	48.8×119.8×71.5	Extra digital output
IB IL AI 2/4-20-PAC	1	12.2×136.8×71.5	Analog input
PR2-RSC3-LDP-24DC/2X21	1	27 ×86 ×78.5	Relay for cutting power supply for the motor in warehouse
UK 6-FSI/C	2	8.2×64×52	Fuses for protecting the circuit of motors
UT 2.5, UT 4-PE	8	5.2 ×47.7 ×47.5	Terminals for expanding the power supply from +24V DC
DIK 1.5	10	6.2×55×54.5	Sensor/actuator terminal block.

According to the size and the quantity of each component, the layout of the control cabinet could be separated in two rows shown in *Figure 9.2*.

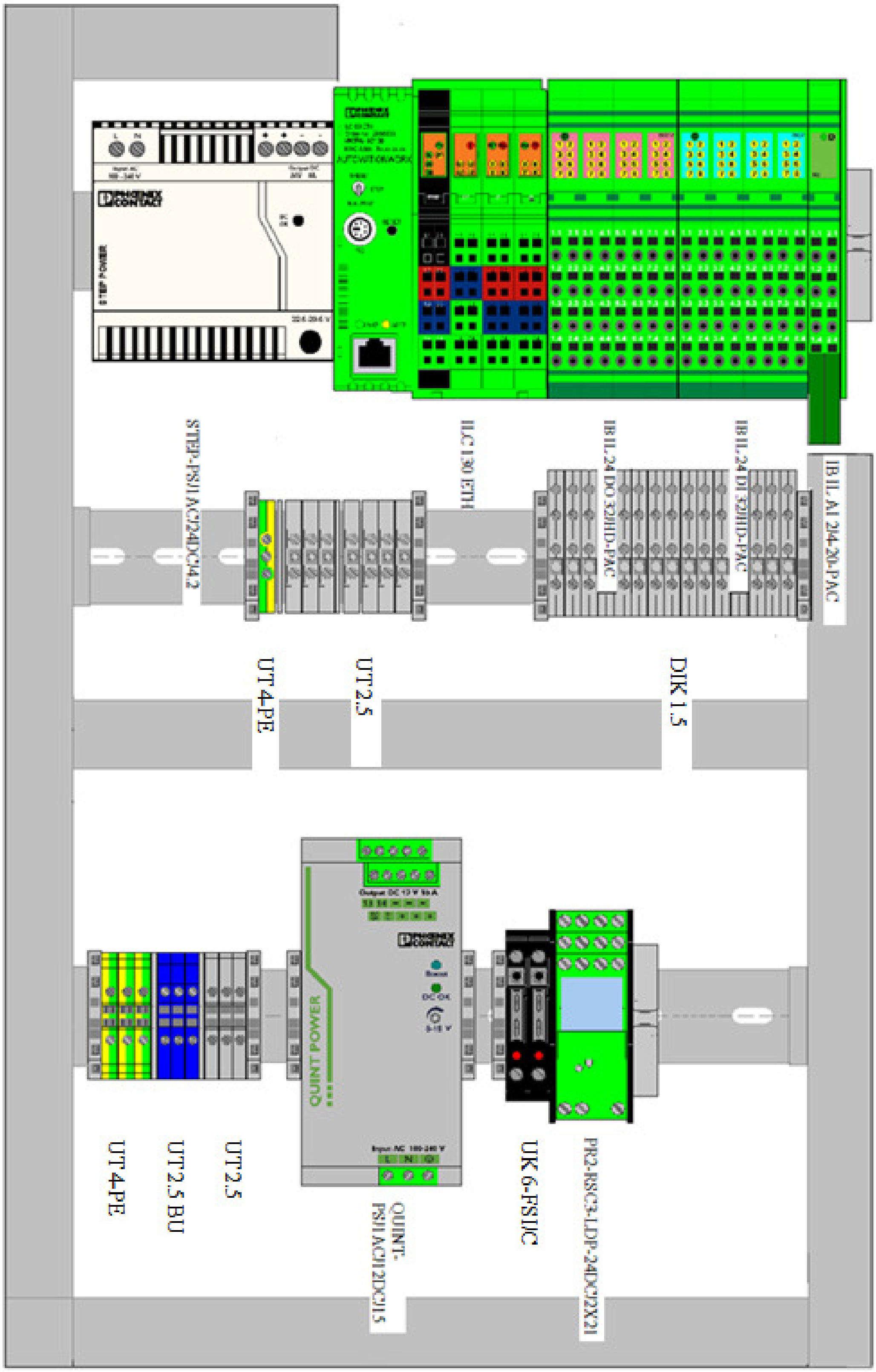


FIGURE 9.2 Layout of control cabinet for version 3.

9.2 LAYOUT DESIGN FOR CONTROL PENDENT

9.2.1 LAYOUT DESIGN FOR CONTROL PENDENT FOR VERSION 1

Before starting the design, the limitation and standard should be clarified. According to control pendent list shown before (*Section 5.1.2*), the type and quantity of each component can be known clearly. Based on *Section 5.1.2*, first, the sizes of all components needs to be used are:

Table 9.3 Component detail list of the control pendent for version 1

Name	Quantity	Size(mm)
Control pendent box	1	80×150×50
Emergency stop	1	Ø30×66
ON-OFF switch	1	23×21×21
Push button	4	Ø20×32
Indicator	2	Ø19×45

After making a draft layout designing, indicator (pilot) light lenses shall be colour-coded with respect to the condition (status) of the machine in accordance with *Table 9.4*. Alternative meanings may be assigned (See IEC 60073) in accordance with one of the following criteria:

- The safety of persons and the environment;
- The state of the electrical equipment.

Table 9.4 Colours for indicator lights and their meanings with respect to the condition of the machine /28/ (SFS-EN 60204-1, 95)

Colour	Meaning	Explanation	Action by operator
RED	Emergency	Hazardous condition	Immediate action to deal with hazardous condition (e.g. by operating emergency stop)
YELLOW	Abnormal	Abnormal condition Impending critical condition	Monitoring and/or intervention (e.g. by re-established the intended function)
GREEN	Normal	Normal condition	Optional
BLUE	Mandatory	Indication of a condition that requires action by the operator	Mandatory action
WHITE	Neutral	Other conditions; may be used whenever doubt existed about the application of RED, YELLOW, GREEN, BLUE	Monitoring

Accordingly, the layout of the control pendent could be designed as *Figure 9.3*.

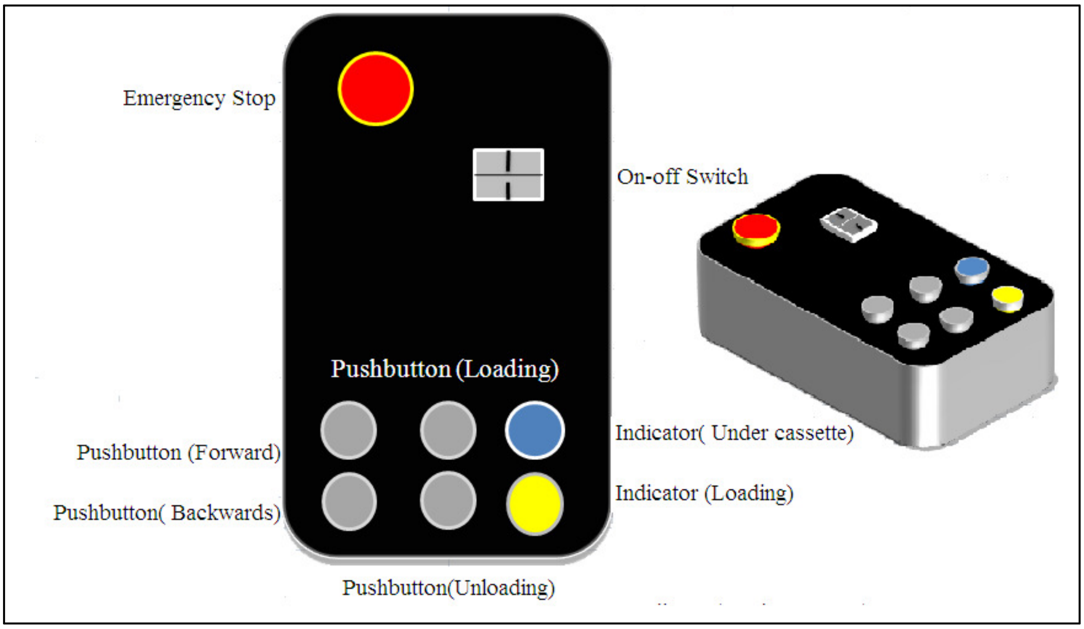


Figure 9.3 The layout of the control pendent for version 1

9.2.2 LAYOUT DESIGN FOR CONTROL PENDENT FOR VERSION 3

Before starting the design, the limitation and standard should be clarified. According to control pendent list shown before (*Section 5.2.2*), the type and quantity of each component can be known clearly. Based on *Section 5.2.2*, first, the sizes of all components needs to be used are:

Table 9.5 Component detail list of the control pendent for version 3

Name	**Quantity**	**Size(mm)**
Control pendent box	1	80×150×50
Emergency stop	1	Ø30×66
ON-OFF switch	1	23×21×21
Push button	4	Ø20×32
Indicator	6	Ø19×45
Potential Meter	1	11×12×54

After making a draft layout designing, indicator (pilot) light lenses shall be colour-coded with respect to the condition (status) of the machine in accordance with *Table 9.4*. Alternative meanings may be assigned (See IEC 60073) in accordance with one of the following criteria:

- The safety of persons and the environment;
- The state of the electrical equipment.

Depending on the quantity and size of each component, the control pendent for version 3 could be designed as follow:

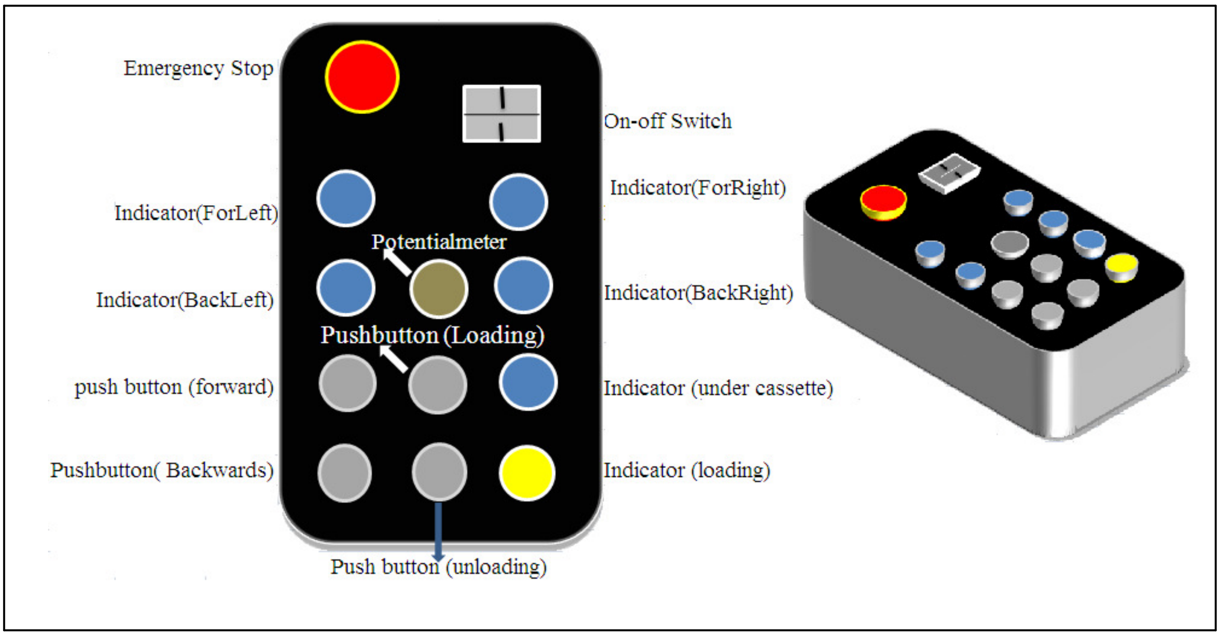


Figure 9.4 The layout of the control pendent for version 3

10 CONCLUSION

As the conclusion, in order to make a continent and fast transportation system depending on different geographical and environmental requirements, the control system for three solutions is successfully designed and commissioned as a small scale model.

According to the differential between the three versions, the benefits are distinct.

Version 1 could be considered as the simplest solution for the issue. In this version, because the vehicle only needs to move on the straight, short and fixed track, the benefit comes as follows:

- Energy can be supplied from the electric network and transformer.
- No need for a wireless control system (which means all the electric components can connect to the control cabinet directly even though the vehicle is moving).
- Just the traction – no need for steering.

Version 2 could be used for transporting in a straight but short path with wireless connection, which means if the path is free, other things can go through optionally. The benefit is no need for complicated mechanical construction for steering.

Version 3 is wireless connection with long distance which means it can be used in a very wide range of the transportation system. However, because it is following a predefined path on the floor, it no need for complicated navigation

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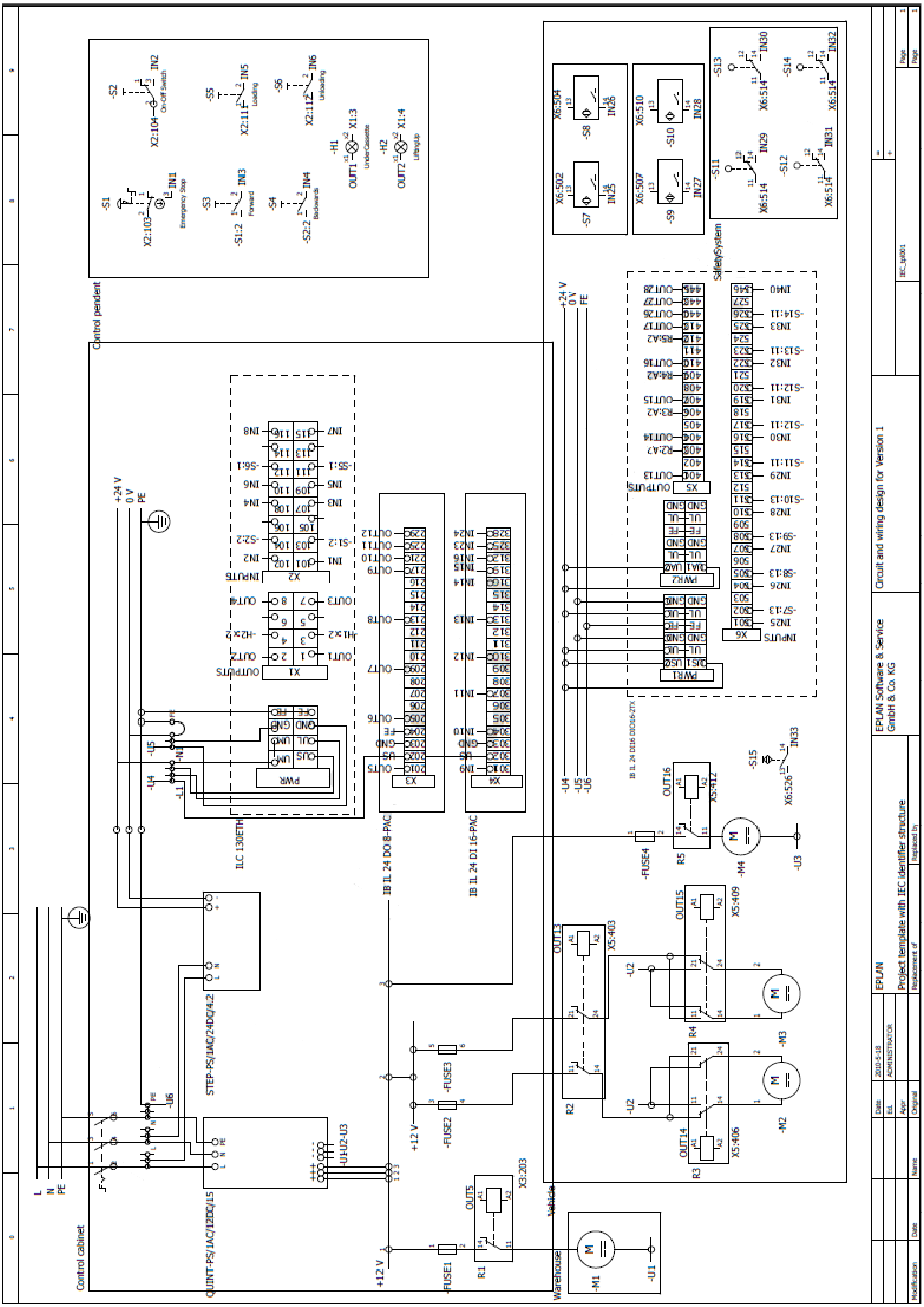
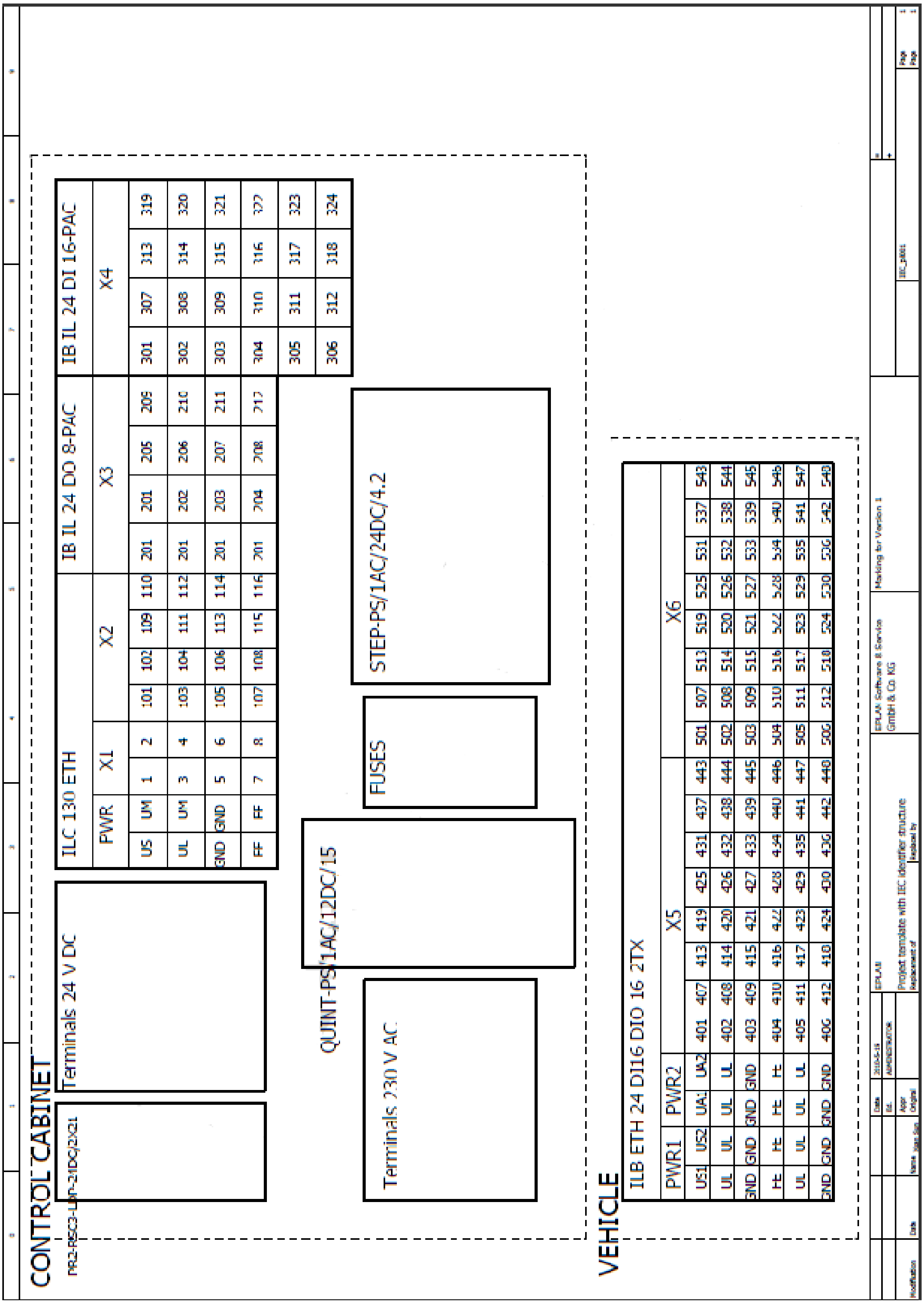
Appendix 1

CIRCUIT AND WIRING DESIGN OF VERSION 1



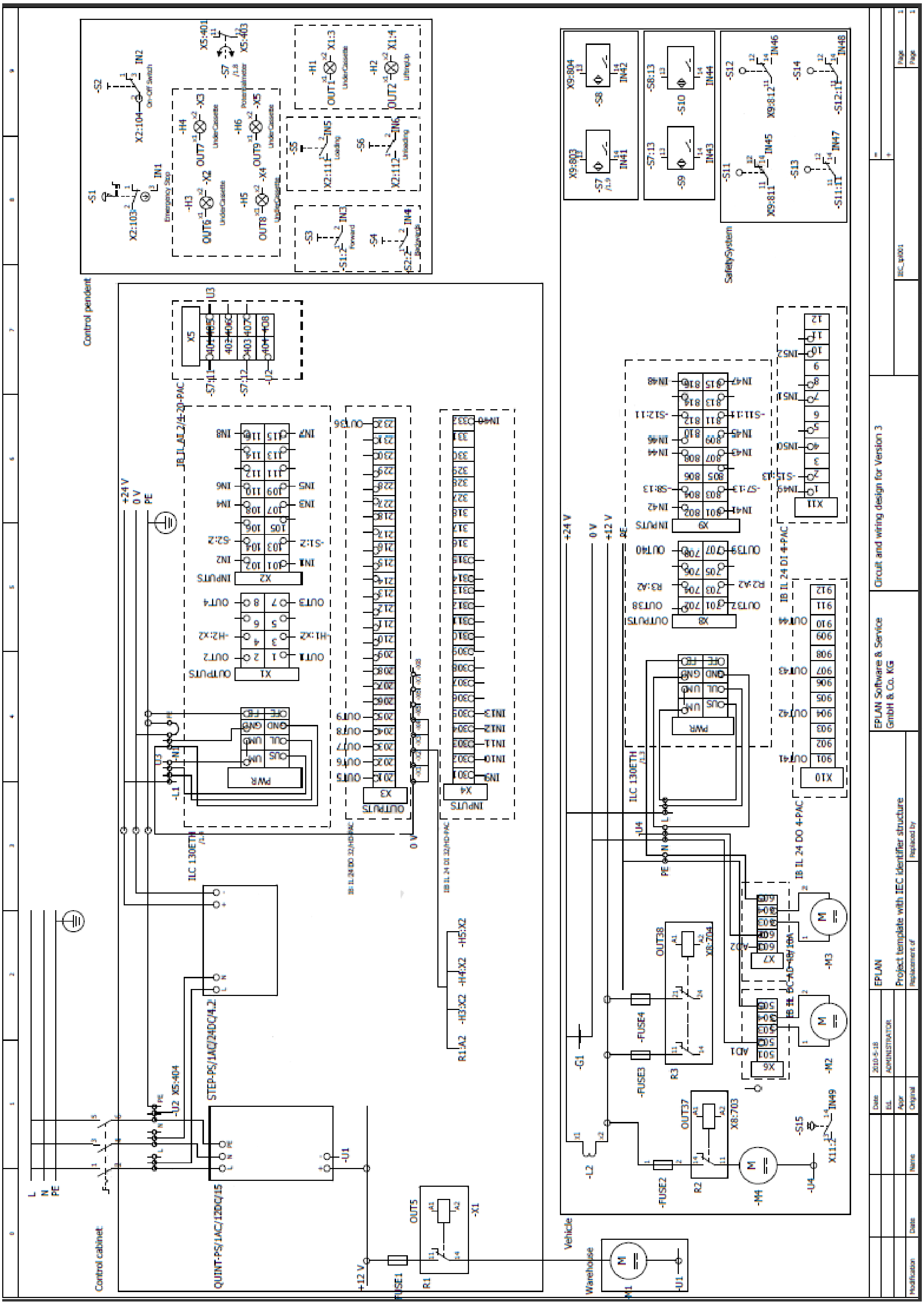
Appendix 2

MARKING OF TERMINAL POINTS IN PLCS FOR VERSION 1



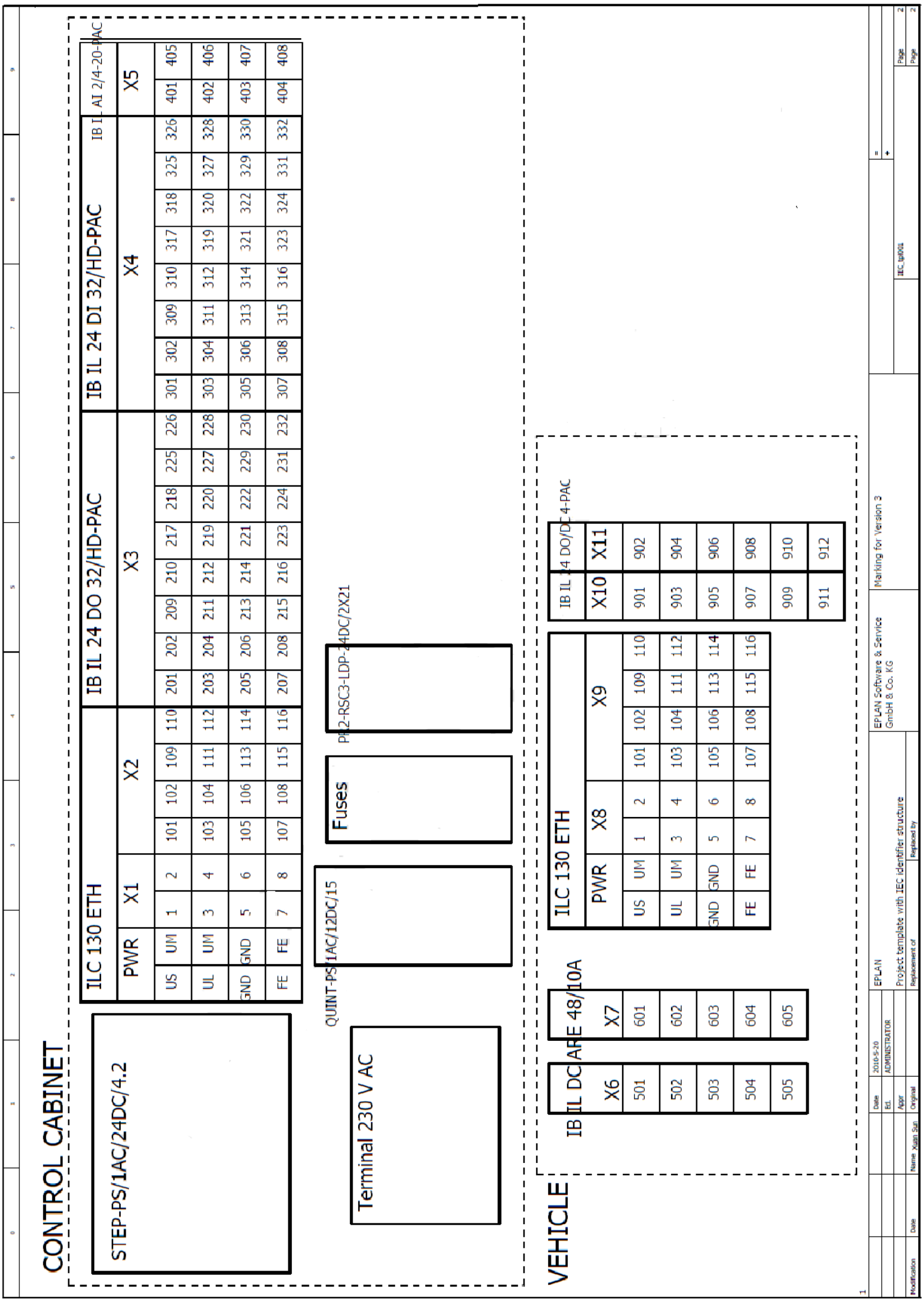
Appendix 3

CIRCUIT AND WIRING DESIGN OF VERSION



Appendix 4

MARKING OF TERMINAL POINTS IN PLCS FOR VERSION 3



Appendix 5

CONTROL CABINET BOX